Volume 33. No. 1 January, 1958

THE JOURNAL OF HORTICULTURAL SCIENCE

(Formerly The Journal of Pomology and Horticultural Science)

Subscription Rates:
SINGLE NUMBERS 20/- EACH
ONE VOLUME (FOUR NUMBERS) 60/- (RATE FOR CANADA & U.S.A., $8.50) POST-FREE

PUBLISHED BY
HEADLEY BROTHERS LTD
109 Kingsway London WC2 England

-7 FEB 1958

Water-regimes.

Four different water-regimes (referred to as " main treatments ") were replicated three times in a randomized block layout. In three of the regimes, A, B and C, plants were not watered until 5, 35 and 50 per cent. respectively of the available soil moisture had been removed from the soil at a depth of 15 cm., as calculated from readings of soil moisture tensions (i.e. when tensions of 7, 15 and 30 cm. mercury had developed). Each plot was watered when its tensiometer indicated the limiting tension, sufficient water being supplied to re-wet the soil throughout the rooting zone to field capacity. In the fourth water-regime, D, the timing of irrigation was based on visible symptoms of incipient wilting and on moisture content measurements of soil samples.

Regulation of fruit loads.

Tomato plants allowed to grow without " stopping " are subject to a considerable " strain " just before the fruits on the lower trusses are harvested, since plants are then carrying a heavy load of fruit and are also making vegetative growth. In the present experiment, plants were subjected to varying fruit loads during this critical period, the number of fruits per plant being regulated by the following methods. Two plants in all plots were subjected to each sub-treatment.

Sub-treatment P (maximum fruit load). The first few flowers on each truss were allowed to set naturally and the remaining flowers were then treated with 2-naphthoxy-acetic acid (BNOA), after the technique of Luckwill (1948) with slight modifications. This treatment resulted in every flower forming a fruit, thus giving a heavy fruit load.

Sub-treatment Q (control). Plants were allowed to set fruit naturally with no attempt to regulate the number of fruits developing.

Sub-treatment R (standard fruit load). The first six flowers on each truss were allowed to set naturally and develop into fruit. All remaining flowers on the truss were removed.

Sub-treatment S (minimum fruit load). A heavy fruit load was obtained on the first truss by treating unpollinated flowers with BNOA and the second, third and fourth trusses were removed before the flowers opened. The plants were thus subjected to a limited fruit load over a relatively short period of time.

Cultural details.

Seed of the variety Potentate was sown on 21st January 1954 and the seedlings were pricked off on 1st February into five-inch clay pots. The plots were thoroughly flooded with water in January and again in early March. A normal commercial dressing of fertilizer was lightly forked into the soil before planting took place on 10th March. " Ball-watering " (see Salter, 1957) was carried out from this time until 10th April. The soil in each plot was then brought to field capacity and differential watering treatments were carried out from this date until the end of the experiment in September.

Manipulation of flowers, to vary the fruit loads, was started on 16th April and continued regularly as each truss developed.

Recording of growth.

In order to obtain a quantitative assessment of possible relationships between vegetative growth, fruit development and water-regimes, detailed measurements of growth were made at weekly intervals. The methods of Ross (1946) were used to correlate plant dimensions with dry weight, leaf area and fresh weight of fruit.

Dry weight increase. As one criterion of growth, measurements of height and mean diameter of the stem were combined by means of a regression equation to give a calculated dry weight of the vegetative aerial parts of the plant. Weekly measurements enabled curves of increases in dry weight to be plotted for each plant. Regression equations obtained from different plants under the four water-regimes were not significantly different; consequently all the data were pooled to give the general regression :

$$y = 0{\cdot}3245x + 1{\cdot}4 \qquad r = +0{\cdot}99 \qquad P < 0{\cdot}01$$

where x = height (cm.) × square of mean diameter (cm.),
y = dry weight (gm.) of the vegetative parts of the plant,
r = correlation coefficient.

Leaf area increase. The use of regression equations relating leaf dimensions to area was considered to be the best method for determining leaf area in the present experiment and the various correlations obtained for the tomato leaf by Porter (1937), Romshe (1942), Ross (1946) and Lyon (1948) were examined. The relationship between the square of the leaf length and the area of the leaf (Ross, 1946) was finally used. Individual regressions obtained from plants under the four water-regimes were again found to be non-significantly different and a general regression equation was obtained :

$$y = 0{\cdot}3218x - 27 \qquad r = +0{\cdot}989 \qquad P < 0{\cdot}01$$

where x = square of length of leaf midrib (cm.),
y = leaf area (sq. cm.).

The lengths of all leaves on the experimental plants were measured monthly and the leaf areas calculated.

Weight of individual fruits. Ross (1946) has suggested that, since the percentage of dry matter contained in tomato fruits of even greatly different ages very closely approached a constant value, fresh weight of the fruit could be used as a reliable index of growth. He correlated fruit dimensions with its fresh weight.

Since the greatest equatorial diameter can readily be measured with slide calipers to the nearest tenth of a millimetre, the relationship between the diameter cubed and fresh weight was determined for fruit from each treatment in the present experiment. Differences between individual regressions were not significant and the data were pooled to give the general regression :

$$y = 0{\cdot}4524x + 1{\cdot}8 \qquad r = +0{\cdot}995 \qquad P < 0{\cdot}01$$

where x = square of diameter (cm.),
y = fresh weight of fruit (gm.).

This correlation enabled the fresh weight of fruits to be calculated without removing them from the plants.

Diameter of individual fruits. To determine the effects of the different water-regimes and of fruit load treatments on the growth of individual fruits, the second flower on each truss was tagged after setting and the greatest equatorial diameter of each of these fruits was measured daily. The second fruit was selected since the final size of a fruit is related to its position on the truss (Gustafson, 1926), and also to reduce the chance of a parthenocarpic fruit being selected for measurement.

Assessment of total fruit load. To determine the increase in total fruit load, on a fresh weight basis, the diameter of each fruit on all experimental plants was measured weekly until harvesting commenced, and the fruit load for each plant calculated.

Hayward (1938) and Ross (1946) found that the percentage of dry matter in the tomato fruit remained approximately constant during growth, whereas MacDougal (1919) stated that the percentage of dry matter gradually fell during development, and Gustafson (1926) supported this view. In the present experiment there was no marked trend in percentage of dry weight of fruit grown under different water-regimes, nor with size or age of the green fruit. Estimates of fruit load on a dry weight basis were therefore obtained directly from the fresh weight figures.

Results.

Vegetative growth.

Dry weight production. Curves showing increases of dry weight for plants grown under all combinations of water-regimes and fruit load are given in Fig. 1, the solid lines indicating dry weights of vegetative aerial parts of the plants during the first fourteen weeks after planting, i.e. until just before harvesting commenced. At this stage the fruit load treatments had affected vegetative growth more than the water-

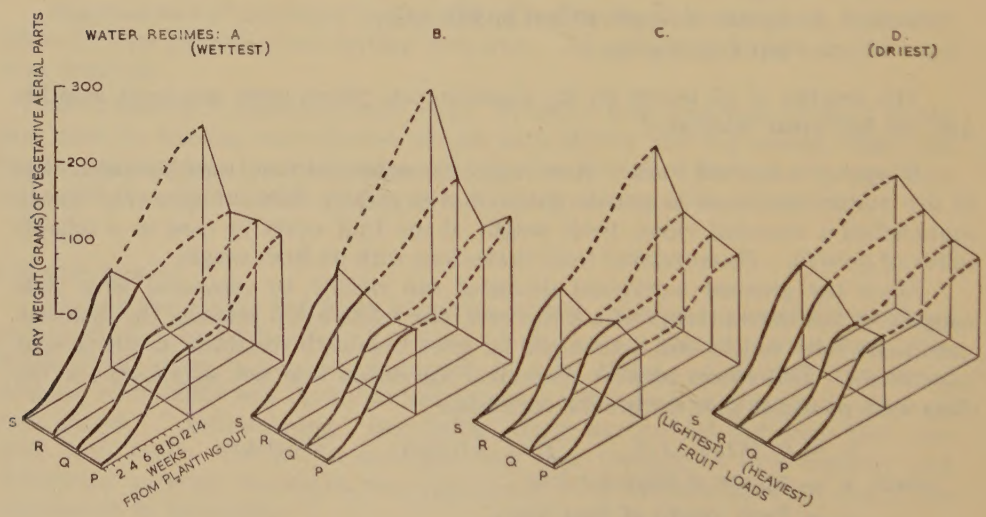

Fig. 1.
Growth of plants under all combinations of treatments, based on dry weights of vegetative aerial parts.

regimes. By means of a statistical technique described by Tukey (1949), calculated dry weights at the 14th week were tested for interactions between main treatments and sub-treatments but none was found. Plants with restricted fruit loads had made the greatest vegetative growth at this stage.

Final dry weights of plants at the end of the season, 28 weeks after planting out, are presented in Table I. Again there were no interactions between main treatments and sub-treatments.

TABLE I.

Final calculated dry weights (gm.) of vegetative aerial parts 28 weeks after planting; means of 2 plants.

Fruit load	Water-regime			
	A (wettest)	B	C	D (driest)
P (heaviest)	165	189	139	128
Q	166	155	143	133
R	154	194	154	154
S (lightest)	244	294	220	173

Growth in height. Although the rate of vegetative growth, measured by dry weight, was reduced as the fruit load of plants increased in all combinations of main and sub-treatments (Fig. 1), when growth was measured in terms of height of stem alone, sub-treatment S (the lightest fruit load) caused little reduction in vegetative growth under any water-regime during the period of maximum fruit development (Fig. 2). This is indicated by the steady slope of the curve from x to y in each case.

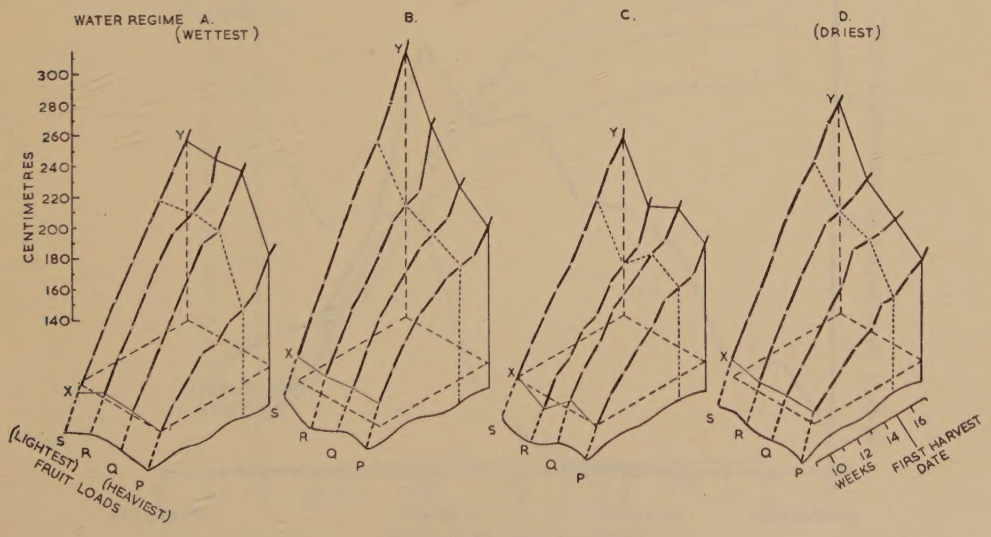

FIG. 2.
Stem growth (height) of plants under all combinations of treatments, during the period of maximum fruit development.

Growth in height of plants in sub-treatments P, Q and R was progressively reduced, as the fruit loads on the plants increased, up to the time when the first fruits were picked (15th week), after which the rate of stem growth began to increase again. This reduction in rate of growth did not occur to the same extent with sub-treatment S (Fig. 1) and growth in height of the stem was unaffected (Fig. 2).

Leaf area. Measurements of leaf areas taken just before harvesting commenced showed no interaction between main and sub-treatments. Final leaf areas from plants under all combinations of treatments are presented in Table II.

TABLE II.

Calculated leaf areas (cm.²); means of 2 plants.

Fruit load	Water-regime			
	A (wettest)	B	C	D (driest)
P (heaviest)	14,940	15,330	14,490	12,950
Q	15,950	13,830	14,490	13,500
R	17,580	16,560	15,470	15,410
S (lightest)	22,520	20,440	18,220	16,270

Tukey's method of analysis was again used to examine the data. It was found that when leaf area was used as a criterion of growth there was an interaction between fruit load S and the water-regimes, but not between other fruit load treatments and water-regimes.

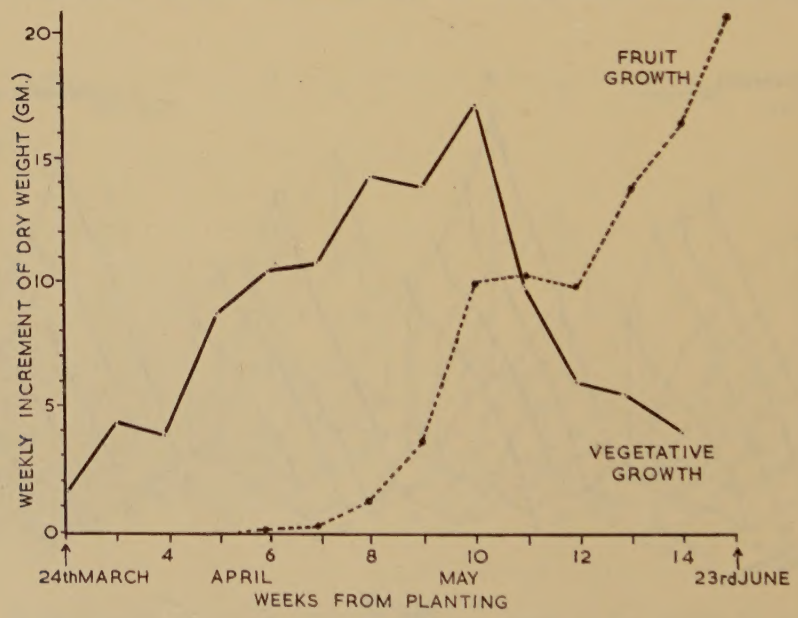

FIG. 3.
Weekly dry weight increment curves for vegetative growth and fruit production.

Correlations between growth of fruit and vegetative parts.

The results presented indicate that different fruit loads had affected vegetative growth by the time harvesting commenced. Many aspects of the fruit load and many environmental and cultural factors were examined in an attempt to determine the critical conditions which caused this correlation between vegetative growth and fruiting, but it was not possible to find any one factor that could be correlated with the reduction in weekly dry weight increment. Number of fruits per plant, fresh weight of fruit per plant, percentage of weekly increment in total dry weight diverted to fruit, stage of development of the first truss and percentage of fruit load nearing maturity were all examined in an attempt to explain the differential vegetative growth with the four fruit loads P, Q, R and S. It was found that the rate of fruit production was reduced during the tenth to the twelfth week, prior to the first harvest, but not to the same extent as vegetative growth (Fig. 3).

Growth of fruits.

The growth rate of individual fruits from different plants during the grand period of growth was calculated in a manner similar to that described by Sinnott (1945). The growth over a period of fourteen days following the attainment of a mean diameter of 8·0 millimetres was taken for comparative purposes and the angle of slope of the growth curve was determined by the method of least squares.

The rates of growth of fruits from the first, second and third trusses of plants grown under all combinations of main and sub-treatments showed no significant

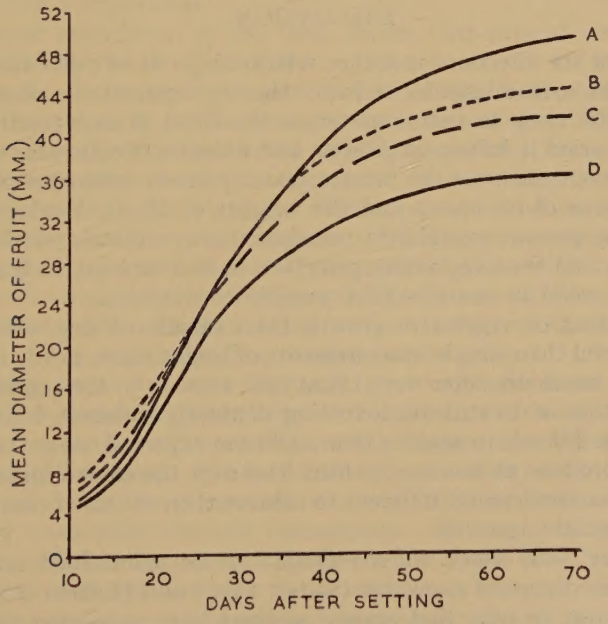

FIG. 4.
Growth curves (diameter) of first truss fruit—standard fruit load (sub-treatment R). For A, B, C and D, see text, p. 2.

differences. Under the conditions of this experiment neither water-regime nor fruit load appeared to have influenced the growth rate of individual fruits during the grand period of their growth. However, this does not imply that fruits were all of the same final size, since the grand period of growth may last for a varying length of time. This is illustrated in Fig. 4, where the different water-regimes are shown to have affected the final size of first truss fruits in plants which had comparable fruit loads (sub-treatment R).

This confirms the results of previous experimental work, which showed consistent effects of different water-regimes on the final size of fruits. Evidence is also presented in Table III (and Fig. 4) to show that total yield and average weight of fruits increased in the wetter regimes as in previous work.

TABLE III.

Total yield and mean weight of ripe fruit from plants under the four water-regimes; means of four sub-treatments.

	Water-regime			
	A (wettest)	B	C	D (driest)
Total yield of ripe fruit per main treatment (kg.)	3·89	3·93	3·02	2·60
Mean weight per fruit per main treatment (gm.)	53·7	50·4	47·2	37·7

DISCUSSION.

In studies of the effects of moisture relationships or of other factors governing the growth of plants, it is desirable to follow the development of a plant progressively throughout its life cycle to determine when the effect of any treatment begins to show, for what period it influences growth, and when its effects cease to be apparent. To follow the development of the tomato plant, periodic estimates of the weight of the plant, the area of its leaves and the weights of all its developing fruits were required. In the present experiment non-destructive methods were used to obtain this information and thus vegetative growth rate and increase in fruit load on any particular plant could be examined for possible correlations.

The assessment of vegetative growth from calculated dry weights was more sensitive and useful than simple measurements of height since, in the former method, both height and mean diameter were taken into account in the regression equation.

The imposition of treatments involving distinctly different fruit loads proved to be rather more difficult to achieve than had been expected, since the use of BNOA did not always produce an increase in fruit load over the control plants. However, the fruit loads were sufficiently different to achieve their object of causing differential responses in vegetative growth.

The accuracy with which water-regimes can be maintained for experimental purposes has been discussed elsewhere (Salter, 1954a and Hudson *et al.*, 1957).

It is of interest to note that several workers have suggested that the growth curves of plants may be characterized by a series of exponential segments, breaks in the curves being related to stages in the growth of the plant. All the growth

curves plotted in Fig. 1 show a double sigmoid curve, although this is more pronounced in some combinations of treatments than in others. The progressive reduction in the rate at which dry weight increased from the tenth to the sixteenth week after planting, and the recovery of the growth rate when picking commenced, are related to the increasingly heavy loads of fruit carried by the plants and to the subsequent removal of parts of the loads at harvest. It has been shown that by the fourteenth week the water-regimes and fruit load treatments are additive in their effect on vegetative growth. The water-regimes were probably only beginning to show their effects by that time (Salter, 1957) and it seems that fruit load treatments were responsible for the more important effects on vegetative growth.

A less satisfactory method of expressing vegetative growth is by measurements of height, but the critical parts of growth curves obtained by plotting heights are shown in Fig. 2. Plants carrying the smallest load of fruit (sub-treatment S) were characterized by a steady increase in height throughout the period prior to harvesting, whereas heavier fruit loads reduced the rate of stem growth by varying amounts. Leonard (1954) quoted many scattered statements by earlier workers at the Cheshunt Research Station to the effect that a mid-seasonal check to the growth of the tomato plants had frequently been observed, although he did not find that stem growth was checked in his own experiments. Went (1944) claimed that rate of stem growth was not correlated with fruit production under optimal growing conditions, but from the data he presented it is clear that the plants were carrying only a small fruit load and a reduction in growth rate was, therefore, not to be expected. Went also cited the work of Arnon and Hoagland (1939) as additional evidence but this paper gives no quantitative data on the rate of stem growth and consequently cannot be accepted as supporting Went's hypothesis.

In the present experiment it has been shown that rate of stem growth was apparently affected by the developing fruit on the plant. In an attempt to place this relationship on a quantitative basis, various characteristics of the fruit load were examined in relation to (*a*) the point of the inflexion of the sigmoid curve for dry weight (approximately the 10th week) and (*b*) the period of reduced stem growth (15th week). A very close correlation was found between the time of inflexion of these curves and that of the development of fruit (mean diameter) of the first truss. This close correlation, which was independent of both water-regime and fruit load treatment, suggested *ipso facto* that the point of inflexion could not be taken as representing a reduction in vegetative growth due to any particular treatment or combination of treatments. Further, many workers have questioned the importance and significance of the point of inflexion of sigmoid curves.

An interesting trend appeared in total dry weight produced by the plants (Fig. 3). Weekly increments of dry weight of vegetative growth and of fruit production increased up to the 10th week, after which the increases in vegetative growth became progressively smaller. From the 10th to the 12th week the rate of dry weight increase of fruits was somewhat checked, after which the rate increased rapidly week by week until harvest commenced. It should be noted that root activity was not studied in the present experiment and thus "total" dry weight refers only to the portion of the plant above the ground.

It is pertinent to mention the results obtained by Cooper (1957) in a similar investigation with glasshouse tomato plants. He found that the weekly rate of growth of all the organs which he studied increased rapidly until May, followed by

a decrease in the development of new roots in early May, of new axillary shoots in mid-May and new fruit in late May. Results obtained in the present experiment support his findings.

No one single factor could be found in the present work to explain the difference in effect of sub-treatment S on stem growth as compared with sub-treatments P, Q and R. The smaller percentage of the fruit load which was nearing maturity on plants of treatment S may have been an operative factor, although the smaller total fruit load in terms of fresh weight and number of fruits may have contributed to the result.

It is now generally accepted that fruiting may cause a reduction in vegetative growth of many plants and it has been suggested by several workers that under sub-optimal conditions the developing fruit is able to monopolize the food resources of the plant (Mason, 1922 ; Murneek, 1924 and subsequent papers). In the present experiment, though vegetative growth was checked to differing degrees under the various treatments, the growth rate of the fruit was not significantly different, a result which suggests that the fruits were able to monopolize the food resources of the plants in order to maintain similar rates of growth under various adverse conditions. Moreover, the mean fruit weights from different fruit load treatments were not significantly different, irrespective of the number of fruits carried by the plants.

For the foregoing reasons it is suggested that the differential check to vegetative growth under the various fruit loads was due to the monopolization of food resources by the fruit. There is little evidence to support the view that fruits secrete a growth-inhibiting substance which retards vegetative growth, although this hypothesis has been suggested to explain some experimental results (McCollum, 1934).

Many workers have suggested that fruit growth responds to different soil moisture conditions within the available water range, but others dispute this view. Results in the present and previous experiments suggest that growth *rate* of the tomato fruit is not sensitive to soil moisture conditions, but that the *duration* of the grand period of growth is affected, with the result that a greater size of fruit is obtained under the wetter regimes.

The experiment reported here has shown that a relationship exists between vegetative growth, fruit development and soil moisture conditions, and it further emphasizes the importance of maintaining the soil moisture high in the available range, especially when a heavy crop of fruit is being carried by tomato plants.

SUMMARY.

An investigation was made to determine the effect of soil moisture conditions on the relationship between vegetative growth and fruit development of the tomato plant under glasshouse conditions.

Greatest vegetative growth was obtained with a small fruit load under conditions of high soil moisture. Conversely, weakest vegetative growth was found with a large fruit load under conditions where the soil was allowed to dry out between irrigations nearly to the permanent wilting point. Water-regimes and fruit load treatments were found to be additive in their effect on vegetative growth.

The experimental results are discussed with reference to previous work and a possible explanation of the results is suggested.

ACKNOWLEDGMENTS.

I am greatly indebted to Dr. J. P. Hudson for the encouragement, interest and advice given during this work, which was carried out under his supervision in the Department of Horticulture.

Grateful acknowledgment is made of a grant from the Agricultural Research Council which has met the cost of this work.

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(*Received* 2/2/57.)

SUSCEPTIBILITY OF RASPBERRY VARIETIES TO INFECTION BY APHID-BORNE VIRUSES

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VARIETIES of crop plants often differ greatly in susceptibility to infection by viruses. Such differences are important both to the grower and, more especially, to the plant breeder because they make possible the selection of varieties resistant to infection. It has long been suspected that some varieties of raspberry are more resistant than others to infection by aphid-borne viruses. Rankin (1927) made extensive studies of the rates of spread of such viruses in red and purple varieties of raspberry in N. America and coined the terms " klendusic " and " klendusity " to describe the tendency of many varieties to escape infection. He used the terms " resistant " and " susceptible " to describe the reactions of plants following infection : susceptible varieties were those which developed severe symptoms, resistant or immune those which developed few or no symptoms or behaved as symptomless carriers. In his terminology, a klendusic variety could be either susceptible or resistant to infection and there seemed to be no correlation between ability to escape infection and severity of symptoms developed in inoculated plants. Rankin's terminology seems unnecessarily cumbersome and in this paper we shall use the terms " resistant " and " susceptible " to refer to the relative frequency with which plants of different kinds become infected by aphid-transmitted viruses.

The aim of the experiments reported here was to find whether present-day commercial varieties of raspberry differ in susceptibility to infection by viruses transmitted by the raspberry aphid, *Amphorophora rubi* Kalt., and to study the pattern of spread of such viruses in the field. The results show that, in eastern Scotland, these viruses spread slowly, even in the most susceptible varieties, and that indiscriminate propagation from healthy and diseased plants is the principal reason for the rapid degeneration of commercial stocks of raspberry.

EXPERIMENTAL RESULTS.

RELATIVE SUSCEPTIBILITY OF VARIETIES TO INFECTION.

Raspberry leaf spot virus.

In April 1953 a trial, of 5×5 Latin square design, was planted in which rows of 10 healthy canes of each of the varieties Norfolk Giant, Lloyd George (New Zealand stock), Malling Landmark, Malling Promise and Malling Exploit were exposed to infection by leaf spot virus (Cadman, 1952b). The healthy canes were from stocks known, by graft-testing, to be free from leaf spot virus and infected only with certain undescribed latent viruses. The infectors were plants of Lloyd George (Amos stock) dug from an old commercial plantation. To facilitate spread of infection

all plants in the trial were spaced 30 inches apart in each direction and the rows of healthy plants were separated by rows of diseased ones ; aphids were allowed to multiply and migrate freely.

Except for Norfolk Giant, all the varieties tested were symptomless carriers of leaf spot virus and spread of infection could be followed only by graft-testing every plant to a suitable indicator host. Potted healthy plants of Norfolk Giant were used for the test and all plants in the trial were indexed first in May 1954 and again in 1955. Plants found to be diseased on these dates were assumed to have become infected sometime during the previous year. The results (Table I) showed

TABLE I.

Susceptibility of raspberry varieties to infection by leaf spot virus.

Variety	Years after planting			
	1 (1954)		2 (1955)	
	Plants infected/ plants tested	Per cent. plants infected	Plants infected/ plants tested	Per cent. plants infected
Norfolk Giant	0/50	0	0/50	0
Malling Landmark ..	1/49	2	10/46	22
Malling Promise	19/46	41	34/47	72
Malling Exploit	29/47	62	41/47	87
Lloyd George	28/44	64	44/49	90

that, after exposure to infection for two seasons, 75 per cent. of the Lloyd George, Malling Promise and Malling Exploit plants but only 20 per cent. of the Malling Landmark and none of the Norfolk Giant plants were infected. The apparent resistance of Malling Landmark is noteworthy and will be referred to again below.

The results with Lloyd George and Malling Promise confirmed those of an earlier trial made in 1947 at Brechin, Angus, where 50 healthy plants of each variety were exposed for two seasons to infection in a commercial plantation of Lloyd George (Amos stock). The numbers of plants, out of 50, found infected in 1948 and 1949 respectively were : for Lloyd George, 11 and 34 ; for Malling Promise, 7 and 28. The results with Norfolk Giant confirm observations made in a yield trial of raspberry varieties planted at Forfar, Angus, in 1947. This trial included a number of rows of Norfolk Giant adjacent to plots of other varieties, all plants of which carried leaf spot virus. After 3 years only 10 of 383 of these Norfolk Giant plants were infected.

Raspberry veinbanding virus.

In 1953 and 1955, batches of potted healthy plants of the varieties Norfolk Giant, Lloyd George (New Zealand stock), Malling Jewel, Malling Promise and Malling Exploit were exposed to infection by means of aphids (*Amphorophora rubi*) that had previously fed for 4 hours on leaves of Lloyd George plants infected with

veinbanding virus (Cadman, 1952a). The Malling Jewel plants were from a stock free from veinbanding virus ; plants of the other varieties were from the sources already mentioned. The aphids were either reared on virus-free raspberry seedlings or collected from plants in the field that were free from veinbanding virus. Each year 100 infective aphids were transferred to one young shoot on each of 5 healthy plants of each variety in an unheated glasshouse ; the experiment was repeated on 4 successive occasions in each year. After feeding for a day on the healthy plants the aphids were killed either by nicotine fumigation or by spraying with insecticide.

In each trial a few plants of both Lloyd George and Malling Jewel developed veinbanding symptoms a few weeks after inoculation. The final scores (Table II), recorded in 1954 and 1956 respectively, showed that the five varieties differed in

Table II.

Susceptibility of raspberry varieties to infection by veinbanding virus.

Variety	Number of plants (out of 20) infected		Total infected
	1953	1955	
Malling Promise	1	0	1
Malling Exploit	0	5	5
Norfolk Giant	3	3	6
Lloyd George	11	12	23
Malling Jewel	11	13	24

susceptibility to infection. Lloyd George and Malling Jewel were the most susceptible whereas Malling Promise seemed more resistant than either Malling Exploit or Norfolk Giant.

The results of a field trial with these same varieties, begun in 1955, tend to confirm those of the glasshouse experiments. Out of 50 healthy plants each of Malling Promise, Norfolk Giant, Malling Exploit, Lloyd George and Malling Jewel exposed to infection, 0, 1, 4, 6 and 7 respectively showed veinbanding symptoms in 1956 ; by 1957, these numbers had increased to 7, 1, 5, 11 and 16 respectively.

Spread of leaf spot and veinbanding viruses in the variety Lloyd George.

An opportunity to follow the spread of leaf spot virus in Lloyd George (New Zealand stock) occurred in 1947 when 4 rows of healthy plants of this variety were planted at West Park, Dundee, next to a collection of raspberry plants, most of which were infected with leaf spot virus. All the rows were six feet apart with the plants spaced at 30 inches within the rows. No insecticides were applied to the plants and large populations of *A. rubi* regularly developed. Each of the 88 Lloyd George plants was indexed for leaf spot virus by grafting to healthy Norfolk Giant plants in early summer in each of the years 1948, 1949, 1950 and 1951. After one year, 8 plants were infected, 5 of them in the row of 26 plants next to the infectors. In subsequent years, virus spread mainly up and down the rows from these initial foci but even after 4 years less than half the total of 88 plants were infected.

At Mylnefield in 1953, a planting of Lloyd George (New Zealand stock) canes was used to study the spread of veinbanding virus in this variety and to find whether spread was decreased by spraying with insecticides to control aphids (*A. rubi*). There were 4 blocks of 10 plots each. The plots were separated from each other by a common guard row and were squares of 7 plants × 7 plants set 30 inches apart in each direction, the centre plant of each plot being a Lloyd George plant infected with veinbanding virus. The spray treatments, described below, were randomized in each block, a total of 16 plots being left untreated to provide information on the normal rate of virus spread. Raspberry canes in rows only 30 inches apart rapidly become unmanageable and it was necessary each year rigorously to hoe out surplus "spawn" canes during the growing season and, in the winters of 1953/54 and 1954/55, to thin out the "stool" canes to two per plant. The experiment began in April 1953 and ended in September 1955.

None of the plants showed symptoms during 1953 but, in the unsprayed plots, 11 did so in July 1954 and a further 32 in July 1955. These plants probably became infected during the growing seasons of 1953 and 1954 respectively, because plants outdoors rarely develop symptoms in the current year of infection. The 1954 records showed that no spread of virus occurred in 7 of the 10 unsprayed plots; spread to a single plant occurred in each of 7 others and to two plants in a further 2 plots, despite the fact that populations averaging 2,000 *A. rubi* per plant were recorded on these plots in August 1953. Of the 11 new infections only 2 occurred in plants not immediately adjacent to the infectors.

In 1955 the numbers of unsprayed plots with 0, 1, 2, 3, 4 and 5 infected plants (including those recorded in 1954) were 2, 1, 4, 4, 3 and 2 respectively. Interpretation is complicated because, in 1954, virus probably spread from the plants infected in 1953 as well as from the original infectors. Nevertheless, only 4 new infections occurred in plants not immediately adjacent to either of these sources although populations of *A. rubi* approached 60 per young cane. Despite the facts that Lloyd George is among the varieties most susceptible to infection by veinbanding virus, that aphid populations were large and that infected and healthy plants were in contact for most of the two growing seasons, virus did not spread farther than three plants distant from the original infectors. The numbers of infected plants in the unsprayed plots increased from 16* to 27 in 1953 and from 27 to 59 in 1954, approximately a two-fold annual increase.

Virus spread in relation to control of *A. rubi*.

The experiment just described was planned to allow comparisons of rates of virus spread in untreated plots with those in plots sprayed once or twice with DDT emulsion or parathion or systox. The DDT emulsion was prepared by adding 25 per cent. (w/v) of the pure chemical to a 50 : 50 mixture of benzene and toluene and applied as a spray containing 0·2 per cent. DDT. The parathion and systox were commercial preparations and both were used at concentrations of 0·1 per cent. active ingredient. The sprays were applied at rates of 250–300 gallons per acre to upper and lower surfaces of leaves of all plants in the treated plots by means of hand-operated knapsack sprayers. The treatments were randomized within

* The number of infector plants introduced.

each block and each was replicated four times. The same plots were sprayed with the same materials in both 1953 and 1954.

Aphid populations were estimated in 1953 by choosing at random 5 plants from each plot and counting the numbers of alate and apterous *A. rubi* on leaves and stems of both fruiting and young canes. The sprays were applied on 24th June and 29th July and counts made on 11th June, 11th July, 27th July and 18th August. In 1954 the raspberry plants were too large for whole plants to be examined and sampling was done by selecting at random 5 plants from each plot and counting the numbers of aphids found on the tallest young cane of each selected plant. The sprays were applied on 21st June and 3rd August and the counts made on 18th June, 29th June, 30th July and 24th August.

A. rubi spends its entire life cycle on raspberry and overwinters as eggs laid in autumn on the young canes. These eggs hatch during April or early May and the fundatrices that develop produce a second generation, a large proportion of which becomes winged. These alatae presumably disperse and establish new colonies. Subsequent generations are largely apterous and the numbers of alatae decline rapidly after mid-July. Sometimes enormous populations of apterae develop. These trends are illustrated by the mean numbers of alatae and apterae per plant and per cane recorded in the unsprayed plots in 1953 and 1954 (Table III).

Table III.

Mean numbers of alate and apterous Amphorophora rubi *recorded on the variety Lloyd George ; numbers per plant in 1953, per cane in 1954.*

Year	Aphids	Sampling dates			
		11th June	11th July	27th July	18th August
1953	alate ..	0	5	4	2
	apterous ..	23	143	711	2,313
		18th June	29th June	30th July	24th August
1954	alate ..	0	0	1	0
	apterous ..	5	17	56	55

In 1953 all three spray materials significantly checked the increase of aphids but they differed greatly in the persistence of their effects (Table IV). Three to four weeks after plots had been sprayed once with DDT emulsion or parathion the numbers of aphids on treated plants did not differ significantly from those on unsprayed plants. After two successive applications of these materials the aphid populations on the treated plants were smaller than on those untreated or sprayed once. A single application of systox, however, kept aphid populations to less than 1/20 of those on unsprayed plants throughout the season and two applications almost

eliminated them. Unfortunately the method of sampling aphid populations in 1954 did not give an adequate estimate of sampling error so that no statistical test

TABLE IV.

Effects of insecticides on populations of Amphorophora rubi *and rate of spread of veinbanding virus in the variety Lloyd George.*

Spraying dates	Sampling dates	Mean nos. aphids per plant in treatments						
		Un-sprayed	Parathion		DDT		Systox	
			once	twice	once	twice	once	twice
1953 Expt.								
24th June	11th June	13	9	34	6	17	19	7
	11th July	125	71	46*	49*	21*	2*	8*
29th July	27th July	740	630	426	524	308	28*	36*
	18th Aug.	1,697	1,905	25*	1,229	117*	68*	8*
Nos. new infections recorded in 1954 per 4 plots ..		3	3	1	1	2	2	0
		Mean nos. aphids per cane						
1954 Expt.								
21st June	18th June	5	5	4	4	4	4	3
	29th June	17	1	0	2	2	0	0
3rd Aug.	30th July	44	36	42	32	36	4	6
	24th Aug.	92	54	2	72	20	18	0
Nos. new infections recorded in 1955 per 4 plots ..		11	8	3	3	5	3	1

* Differences between sprayed and unsprayed plots significant at 1 per cent. level ($P<0{\cdot}01$).

of the differences between treatment means is possible. The trends, however, were similar to those found in 1953 and there seems little doubt that systox was again the most effective of the three insecticides.

Too few plants became infected with veinbanding virus for the effects of the treatments on virus spread to be analysed statistically and the results are therefore inconclusive. However, virus spread least in plots sprayed twice with systox and the figures (Table IV) show that, in both years, the fewest aphids were found on plants so treated.

DISCUSSION.

These results show that raspberry varieties differ greatly in susceptibility to infection by both leaf spot and veinbanding viruses. Of the varieties tested, Lloyd George, Malling Exploit and Malling Promise seem the most susceptible and Malling Landmark and Norfolk Giant the most resistant to leaf spot virus. The behaviour of Malling Landmark is interesting because this variety is known to be resistant to infestation by *Amphorophora rubi* (Harris and Cadman, 1950 ; Kronenberg and de Fluiter, 1951). Whereas other species of aphids, such as *Aphis idaei* v.d.G. and *Macrosiphum euphorbiae* Thomas, breed freely on Malling Landmark, *A. rubi* does not. The ability of Malling Landmark plants to escape infection may result from the reluctance of *A. rubi* to feed on them or from some innate resistance to infection by means of aphids. Grafting experiments have however shown that leaf spot and other viruses transmitted by *A. rubi* readily multiply in Malling Landmark plants (Cadman, 1952b). It would, therefore, be interesting to know whether Malling Landmark can readily be infected by means of the N. American strain of *A. rubi* which lives and breeds freely on plants of this variety (Hill, personal communication). The resistance of Norfolk Giant to virus infection is not matched by any distastefulness to *A. rubi* because we have frequently used plants of this variety for maintaining cultures of this aphid.

The results of the experiments also suggest that raspberry varieties differ in susceptibility to infection by different viruses. Malling Promise and Malling Exploit resisted infection by veinbanding more than by leaf spot whereas Lloyd George seemed equally susceptible to both viruses. Many attempts have been made (Cadman, unpublished) to use raspberry (*R. idaeus*) seedlings as test plants in experiments on the transmission of viruses, including leaf spot and veinbanding, by *A. rubi* : very few transmissions were obtained under conditions where every plant of the susceptible *R. occidentalis* L. became infected. Altogether, the results imply that plants of *R. idaeus* resist infection by viruses transmitted by *A. rubi.*

Spraying with insecticides may prove a useful means of preventing plant-to-plant spread of virus in raspberry cane nurseries but is likely to be impracticable in fruiting plantations and will not protect plants from infection brought in by aphids migrating from sources outside the crop. Roguing would still seem to be the simplest and most efficient means of controlling spread of obvious mosaic diseases in raspberry.

Despite the relatively slow rate of virus spread, rapid deterioration of healthy raspberry stocks caused by aphid-transmitted viruses does occur in commerce. This is because the majority of growers still propagate canes by methods which result in the relatively rapid spread of virus within crops. Planting material usually consists of canes dug from two-year-old fruiting plantations because it is necessary to remove surplus canes from them ; this means that canes are dug indiscriminately from both healthy and diseased plants. Spread of virus both between and within fruiting plantations occurs because roguing is impracticable, and diseased and healthy stocks of the same or different varieties must, for practical reasons, often be planted side by side. The result is that a proportion of the canes taken from such plantations is always diseased and new fruiting plantations therefore begin with infected plants scattered randomly through them. Assuming that virus spread by aphids doubles the number of infected plants annually, a rough calculation shows that only three 2-year cycles of cane propagation and virus spread are needed to

increase the proportion of infected plants in a crop from 1 to near 100 per cent. Under these conditions, only stocks of the most resistant varieties, such as Norfolk Giant, escape total infection ; those of susceptible kinds, such as Malling Jewel and Lloyd George, will become totally virus-infected in the space of 5 or 6 years. This is borne out by the history in eastern Scotland of the Lloyd George variety which deteriorated within 10 years of its introduction to that area.

Elimination of sources of virus infection within crops would do most to decrease the spread of virus and the loss of crop which it entails, and there is little doubt that this could best be achieved by encouraging fruitgrowers to use virus-free canes for planting in preference to those culled from disease-ridden crops. Possibly a more lasting remedy is to breed new varieties of raspberry that resist infection by viruses. Whatever the difficulties of producing new seedlings of acceptable commercial quality and resistant both to infection by viruses and to infestation by *A. rubi*, sources of resistance undoubtedly exist among cultivated varieties of raspberry.

SUMMARY.

Field and glasshouse experiments with two raspberry viruses transmitted by *Amphorophora rubi* Kalt. showed that raspberry varieties differed greatly in the frequency with which plants became infected. Of the varieties tested, Norfolk Giant seemed the most resistant and Lloyd George the most susceptible, but raspberry plants are relatively resistant to infection and both viruses spread only slowly, even in Lloyd George. Spraying plants of this variety with systox decreased the population of *A. rubi* more than by spraying with DDT emulsion or parathion ; spraying with systox also appeared to decrease the spread of veinbanding virus.

ACKNOWLEDGMENTS.

We wish to thank Miss K. S. Anderson and Miss M. Milne for technical assistance and Mr. M. J. R. Healy of Rothamsted Experimental Station for help with the statistical analysis of the insecticide experiment.

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(*Received* 15/2/57.)

THE ROOT DEVELOPMENT OF BLACK CURRANTS UNDER STRAW MULCH AND CLEAN CULTIVATION

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FEW studies of the effect of straw mulch on the root systems of fruit plants have been reported. Yocum (1937), working in Nebraska, U.S.A., found that apples grown in mulch had a pronounced shallow lateral root development. Bechenbach and Gourley (1932) reported that many roots of apple trees grow on the soil surface just below a deep mulch ; they found, however, as many roots in the soil under mulch as under unmulched trees. The present paper refers to studies on the roots of black currant bushes, in plots of a trial of the effects of straw mulch and clean cultivation carried out by Wakil (1952) to obtain data on growth, yield and soil conditions.

Material and methods.

The variety chosen for study was Wellington XXX because this had shown the greatest contrast in Wakil's trial. The bushes, planted in 1945, were eight years old at the time of excavation and had been under mulch and clean cultivation treatments for 2½ years, before which they were all clean cultivated.

The soil was a freely drained loam, overlying Ragstone at 4 to 5 feet, and consisted of light river drift overlying sandy clay at 2½ to 4 feet deep. A chocolate-brown clay layer a few inches thick was present just above the rock. Furneaux (1954) mapped the area as Barming Series, though parts of the profile could be considered transitional between this and the Malling Series.

Bushes in straw mulch had received 8 tons per acre of straw in January 1950 and 4 tons per acre in the two subsequent winters. No cultivations were done, though patches of couch grass (*Agropyrum repens* Beauv.) were forked out on several occasions. The alleys between rows in clean cultivation were ploughed each winter and cultivated at intervals during the summer, and weeds in the rows were controlled by forking and hand hoeing. In August 1952, at the end of Wakil's experiment, the straw was removed from mulched plots and from then until October 1952, when root studies began, both straw-mulched and cultivated plots were equally left without cultivation and without mulching treatment. Root studies were completed by December 1952. The bushes were spaced at 8 feet between rows and 5 feet between bushes in the row. They had received orthodox pruning treatment.

The roots of one bush from each of the two treatments were excavated in full and those of three bushes under each treatment were studied by sampling methods.

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As Wakil reported, the mulch treatment markedly increased bush size, and this may have affected the size and spread of the root system. The branch size of the excavated bushes was as follows :

Clean cultivated : height, 0·85 m. ; spread, 1·00 m.
Straw mulch : height, 1·20 m. ; spread, 1·35 m.

The detailed excavations were made by the " skeleton " method of Rogers and Vyvyan (1928). Each excavation was extended so as to include the nearest roots of neighbouring bushes and thereby show up any differences that might arise in bush-to-bush competition under each treatment. Root plans were made.

The root samples from other bushes were taken with a modified " needleboard " of the type described by Goedewagen (1948). This is a wooden block fitted with steel rods and is used to hold a block of soil and roots taken from the face of a small trench. The roots are washed out in a tank of water. The dimensions of the block used in this study are shown in Fig. 1. Using this method, samples were taken along the row, within the main root zone, the nearer edge of each sample being 50 cm. from the bush centre (" row " samples) ; also at 110 cm. from the bush centre, i.e. on the midway line between rows. On the cultivated plots the former came from soil not ploughed since planting and the latter from soil regularly ploughed 4–5 in. (about 12 cm.) deep.

Results.

Root excavations.

Under straw mulch there were more large roots coming from the base of the bush than under clean cultivation, but they were less branched in the vicinity of the bush. Under cultivation a mass of fibrous roots just below the soil surface extended outwards about 20 cm. from the base of the bush. This was not present under mulch, being replaced by many vigorous roots, relatively unbranched, which grew out more or less horizontally. Farther from the bush centre, under cultivation, both spreading roots and roots growing upward from below into the top 15 cm. of soil in the alleys had been cut off by ploughing or cultivating. Under straw mulch, many roots grew up into the soil which was under cultivation prior to application of the mulch, and into the mulch itself. There were more deep roots on the bush under cultivation and the maximum depth of rooting was greater.

As it was not possible to reconstruct the original root systems, scale models* were made from the root plans and photographed (Fig. 2).

Root spread and competition between bushes. The effect of the treatments on the root spread of the excavated bushes and the relation between the roots of these and those of adjacent bushes are shown by root plans (Fig. 3). Estimates of the area of

* The method of producing scale models of excavated root systems was as follows. The main and branch roots were represented by bundles of wire varying in size according to their thickness and these were arranged in their correct relative positions by using the information on position and depth of roots as recorded on the root plans. In reducing the scale it was necessary to leave out the smaller recorded roots. Rectangular metal frames 40 in. × 40 in. × 8 in. deep were made of $\frac{1}{2}$ in. × $\frac{1}{8}$ in. angle iron welded together at the corners. A 2-in. square wire mesh was constructed at top and bottom of the frame. To represent roots, bundles were made of 22-gauge soft iron wire which was covered with paper to a thickness of 1/10 in. The top of the frame indicated soil level and a wire bundle of the correct size was fitted in the centre to represent the junction of branches and roots. The wires were separated into smaller bundles for the main roots and these were divided as necessary to indicate root branching.

root spread were made from the field plans by counting the number of half-metre squares containing roots ; these gave the following results :

Straw mulch, 5 square metres (approx.),
Clean cultivation, 3·75 sq. metres (approx.).

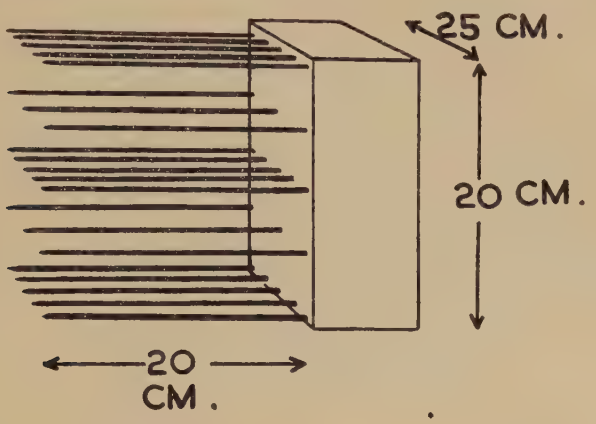

Fig. 1.
The modified " Needleboard " used for taking root samples.

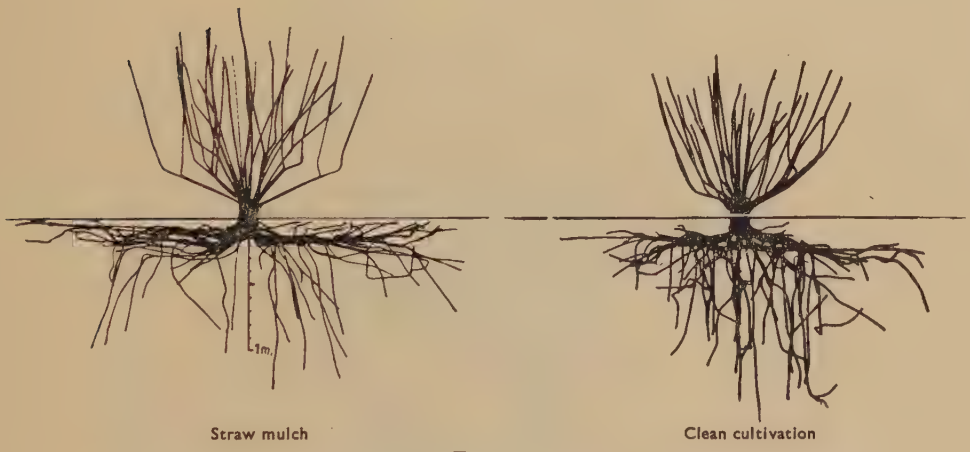

Fig. 2.
Models of excavated bushes showing habit and extent of branch and root systems.

Roots of the excavated bush under straw mulch had competed strongly with neighbouring bushes in the row, but roots of the cultivated bush had interlaced little with those of its neighbours (Fig. 3). Under straw mulch the whole area of soil contained roots, but under cultivation there appeared to be a strip of unexploited soil between rows. Under mulch, the further extension of rooting between rows was particularly marked in soil shallower than 15 cm., i.e. soil which had previously been regularly disturbed by cultivation.

Straw mulch

Clean cultivation

FIG. 3.

Root plans of excavated bushes. The dotted lines represent roots of neighbouring bushes, the circular broken line represents branch spread and the straight broken lines the middle of the rows.

Root sampling.

Roots from sample blocks taken from different depths and positions in relation to the bush were separated from the soil and an assessment of root activity made by counting the number of unsuberized roots present. Unsuberized roots were translucent creamy-white in appearance, approximately $\frac{1}{2}$–1 mm. in thickness and up to 3 cm. long, and grew mainly as laterals on older suberized roots. In some roots the cortical and epidermal tissues were apparently intact, but a brown colour indicated the onset of suberization and the root tip no longer seemed to be active. Such roots were not counted.

Row samples. The distribution of unsuberized roots under each treatment is shown in Fig. 4. Near the surface more roots were found under straw than under clean cultivation, but below 10 cm. depth the converse obtained. The differences were significant at a level of $P < 0{\cdot}01$ at the 0–5 cm. and 30–40 cm. depths.

Alley samples. In the centre of the alleys, in cultivation, there were no roots shallower than 10 cm. deep, but under straw mulch there was much root activity above this depth (Fig. 5). In the alleys, under cultivation, many samples below

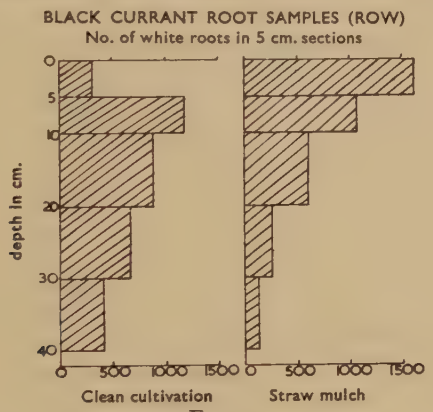

Fig. 4.

Row samples. Relative distribution of unsuberized roots.

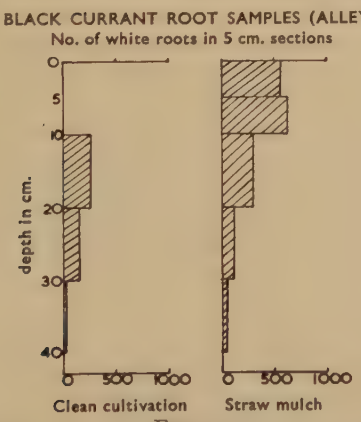

Fig. 5.

Alley samples. Relative distribution of unsuberized roots.

10 cm. contained no roots, and the data illustrated in Fig. 5 are the means of all samples taken at this position. At this sampling position, straw mulch gave an increase of approximately 140 per cent. in the number of unsuberized roots compared with clean cultivation. Of this increase all but 3·2 per cent. was in the 0–10 cm. depth region, which, under cultivation, was ploughed and cultivated.

DISCUSSION.

The effect of straw mulch on the distribution of root activity, as shown by the density of unsuberized roots, has two components. There is the effect on soil moisture associated with mulching and the effect due to cessation of soil cultivation.

Samples taken along the rows compared rooting in mulched uncultivated soil with that in unmulched soil which was virtually uncultivated. This gave a reasonable comparison between root activity in mulched and bare soil. Under mulch, most root activity was near the soil surface and the amount was reduced with increasing depth, whereas under bare soil the level of root activity was greatest from 5–10 cm. deep and was less reduced with increasing depth than under mulch. Thus there were fewer deep roots under straw mulch. These conclusions are similar to those derived from excavating whole bushes. Rogers (1939) has shown that high soil moisture tensions limit root growth, and the mulch effect is probably produced by a lessening of the surface drying which normally occurs in bare soil. As a result, other chemical and physical factors which are more favourable to root growth near the soil surface than in the deeper layers can produce their full effect without being limited by shortage of moisture. A reduced temperature fluctuation may also play a part.

The presence of the shallow fibrous mat close to the bush under clean cultivation and its absence under mulch may be related to surface soil moisture conditions. Under mulch many shallow roots grew out horizontally from the base of the bush. Under cultivation it is probable that shallow roots which grew out from the base of the bush were protected at first from drying out by the dense shade existing below the bush centre. Farther from the bush the tips of these shallow roots would be exposed to drying conditions and this, as well as surface cultivation, would prevent further extension of a particular root axis. When moister conditions supervened, lateral roots would be produced and a branched fibrous condition would result.

The effect of the mulch in reducing activity of the deeper roots is not easily accounted for. Wakil (1952) pointed out that, under mulch, the soil is moister than under clean cultivation and less water is required to raise it to field capacity. It might be expected that the resultant deeper penetration of summer rains would increase the activity of deeper roots, but this did not happen in the present studies. However, Rogers and Vyvyan's (1934) findings on the constancy of the stem/root ratio on a given soil suggest that a relatively greater development of shallow roots would take place at the expense of the growth of deeper roots and this would account for the results observed.

Under bare soil conditions the highest level of root activity was found between 5 and 10 cm. deep and this indicated that, apart from moister soil conditions under mulch, the inter-row cultivation (to a depth of 10–12 cm.) had greatly reduced root development in the region of potentially densest rooting. In addition, a number of main roots of the cultivated bush had been cut by inter-row cultivations where they

grew towards the alleys and sampling data showed that the increased lateral root spread under mulch took place mainly in soil which was stirred when in cultivation. This is similar to the observation made by Adriance and Hampton (1949) on citrus, and by Breviglieri (1952) on cherry, that deep cultivation restricts root spread.

The effect of straw mulch on the growth of black currant bushes was considered by Wakil (1952) to be due to the conservation of moisture by the mulch in sufficient quantity to affect shoot growth. The opinion is put forward by the author that both the modification of root distribution by straw mulching and its restriction by cultivation would give rise to other factors affecting the growth of the bush, irrespective of the moisture conservation properties of the mulch. The greater area of root spread observed would enable the bush to draw on rain falling over a wider surface area of soil and the greater activity of shallow roots would more efficiently exploit the surface soil, which generally contains more nutrients than are present in the deeper layers.

The extent to which the root system of black currants was modified by a change in soil management for only $2\frac{1}{2}$ growing seasons emphasizes the adaptability of their root systems.

SUMMARY.

1. From whole bush excavations of black currants and from root sampling at selected positions, it was concluded that presence of a straw mulch increased the activity of shallow roots and reduced activity of deep roots as compared with clean cultivation.

2. Clean cultivation to 12 cm. deep restricted root growth both in lateral spread and in extension towards the soil surface. From the point of view of root growth, shallower cultivation would have been desirable.

3. The differences are discussed in relation to soil conditions.

ACKNOWLEDGMENTS.

I would like to express my thanks to Dr. W. S. Rogers for his interest and guidance throughout this work, to Mr. J. E. Goode for much valued assistance in describing the soil profiles and to Mr. E. Y. Jones for the photographs.

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(*Received* 21/2/57.)

APPLE ROOTSTOCK STUDIES: THIRTY-FIVE YEARS' RESULTS WITH LANE'S PRINCE ALBERT ON CLONAL ROOTSTOCKS

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East Malling Research Station

DURING the course of his rootstock investigations at East Malling, Hatton tested in the field some twenty-two distinct, vegetatively propagated, apple rootstock clones budded with the culinary variety Lane's Prince Albert. The last report upon this rootstock trial covered the first sixteen years (Hatton, 1935).

Growth and cropping data are now presented for a further 19 years, up to the age of 35 years (1920–1954 inclusive). Special attention is given to six rootstocks that have been found of particular value in England (Bagenal, Garner and Hatton, 1937 ; Garner, 1945). These six rootstocks are now known to fall into five distinct vigour groups : M.IX, dwarfing ; M.VII, semi-dwarfing ; M.IV, moderately vigorous ; M.I and M.II, vigorous ; and M.XVI, very vigorous (Figs. 1 and 2). The comparative behaviour of some other rootstocks that are of special interest elsewhere is also discussed. The vegetatively raised Free stock OF5, a Long Ashton selection, has been renamed L.A. G8.

Plot history.

The trees were planted as maidens in January 1920 on a sandy loam of the Malling Series (Furneaux, 1954). Trees on each rootstock were distributed on either side of a line running east and west across the plot, thus giving some replication. The plot has been clean cultivated, with autumn weeds allowed to grow, and there has been no differential spraying or manurial treatment ; the trees have been grown as open-centre bushes and established-spur pruned. Drastic spur thinning was carried out in 1950, one-third of the total number of spurs on each tree being removed because of their age and length and because of reduced shoot growth.

Some trees were removed in 1946 because those on very vigorous rootstocks were overcrowded. Some of the half-standard trees of Grenadier, planted as pollinators in 1922, were removed in 1951 and the remainder in 1954. To provide for pollination after the removal of the Grenadier trees, some remaining rows of Lane's Prince Albert were frameworked to Howgate Wonder during the years 1952–56.

Observations on the trees of Lane's Prince Albert that were removed and on those remaining did not show any serious amount of scion-rooting.

The trees remaining after thinning were tested during the period 1952–54 for

rubbery wood and apple mosaic viruses. The double-budding method described by Pennypacker and Cropley (1954) was used, and the resulting stocks tested by the hand-budding method for rubbery wood (Prunus type). On the basis of these tests all trees were found to be free from apple mosaic and free to be infected with rubbery wood virus. Most trees on M.IX had died out, M.III and M.V the disease has not impaired the trees' growth and cropping.

Results

A summary of the growth and cropping of trees on all rootstocks in the trial together with the number of trees before and after thinning, is shown in Table 1.

Table 1

Summary of growth and cropping of Long's Prince Albert on twenty-three clonal rootstocks

Rootstock	Number of trees		Area trunk cross-section (sq. cm.) at 15 years	Total crop per tree (bushels*) at 15 years	Relative crop (1.0 = standard) area, age etc.
	Before thinning	After thinning			
M.I	20	12	462	124	1.1
M.II	20	18	574	144	1.4
M.III	18	11	382	84	0.8
M.IV	6	6	321	75	0.7
M.V	20	17	574	149	1.4
M.VI	20	16	418	96	1.0
M.VII	18	15	522	132	1.3
M.VIII	8	7	198	52	0.5
M.IX	11	11	276	68	0.7
M.X	20	13	396	112	1.1
M.XI	9	5	151	41	0.4
M.XII	20	20	588	164	1.6
M.XIII	20	15	450	124	1.2
M.XIV	5	4	222	56	0.5
M.XV	15	12	333	96	0.9
M.XVI	20	17	462	132	1.3
Crabs					
A	5	5	321	92	0.9
C	4	2	172	44	0.4
E	4	2	168	44	0.4
F	4	3	252	72	0.7
H	2	2	192	52	0.5
L.A. 58	4	4	336	92	0.9

* 1 bushel = 40 lb.

Significant differences are not given in this paper since the trial was not designed for statistical analysis, but the large numbers of trees planted on each rootstock have helped to make the contrasts clear.

Tree vigour has been recorded by annual measurements of trunk girth, by periodic measurements of height and spread on all trees and by occasional measurements of shoot growth on selected trees.

Shoot growth.

The annual shoot growth made by trees on M.I, II, IV, VII, IX and XVI during the thirty-five year period showed several interesting features (Table II); firstly, the early vigorous shoot growth produced by trees on M.IV, comparable in amount with that from trees on the very vigorous M.XVI; secondly, the reduction in shoot growth of trees on M.IX, M.IV and M.VII from the tenth year after they had come into heavy bearing, slowly followed by trees on the vigorous M.I and M.II. Shoot growth on trees on M.VII, M.I and M.XVI increased markedly during the last five years (31st–35th years) and the measurements were very similar to those recorded during the previous period but one (21st–25th years). It seems that the trees were beginning to benefit from the drastic spur-thinning and the increased room resulting from tree-thinning in the twenty-seventh year, such benefit having been delayed, no doubt, by two severe summer droughts in the twenty-eighth and thirtieth years.

TABLE II.

Total new shoot growth in 5-year periods and grand total for 35 years (1920–1954) to nearest metre per tree.

Years	1–5	6–10	11–15	16–20	21–25	26–30	31–35	Total for 35 years
Rootstock:								
M.IX	33	140	52	94	156	99	100	674
M.VII	85	430	112	213	301	213	315	1,669
M.IV ..	106	655	269	337	696	548	426	3,037
M.II	60	461	689	574	658	403	308	3,153
M.I	85	624	672	466	392	359	480	3,078
M.XVI ..	111	915	1,043	955	1,433	1,202	1,523	7,182

Area of trunk cross-section.

The measurements of trunk cross-sectional area show clear differences between the vigour groups into which the six rootstocks fall (Table III).

TABLE III.

Mean area of trunk cross-section; trees 35 years old.

Vigour group	Dwarfing	Semi-dwarfing	Moderately vigorous	Vigorous		Very vigorous
Rootstock ..	M.IX	M.VII	M.IV	M.II	M.I	M.XVI
Sq. cm. ..	84	202	291	370	401	493

There have been important changes in the relative order of rootstocks, in respect of tree size, at different periods during the trial (Table IV).

TABLE IV.

Order of rootstocks for trunk cross-sectional area and accumulated crop per tree from 5th to 35th year.

	Tree size (trunk cross-sectional area)				Accumulated crop				
Age	5	10	15	35	5	10	15	20	35
Smallest ..	IX	IX	IX	IX	XVI	IX	IX	IX	IX
	II	VII	VII	VII	I	II	II	VII	VII
	VII	II	IV	IV	IV	XVI	VII	II	II
	I	IV	II	II	II	VII	XVI	IV	IV
	IV	I	I	I	VII	I	IV	I	I
Largest ..	XVI	XVI	XVI	XVI	IX	IV	I	XVI	XVI

Between the fifth and tenth years, trees on M.VII and M.I fell into their present positions relative to trees on M.XVI and M.IX, which have remained throughout the trial the largest and smallest trees respectively. Between the tenth and fifteenth years, trees on M.II overtook those on M.IV. Since the fifteenth year there has been no change in the order of rootstocks for tree size.

Height and spread.

Measurements of tree height and area of branch spread at fifteen years of age (Table V) show good agreement with the order for tree size as based upon the area of trunk cross-section made in the same year (Table IV). By the thirtieth year, however, there was evidence that branch spread had been restricted by overcrowding of the trees ; by the thirty-fifth year trees on all rootstocks, except M.I, were beginning to benefit from the tree thinning that had taken place in the twenty-seventh year (Table V). The special case of the trees on M.I will be discussed later.

TABLE V.

Tree height (m.) and area of spread (sq.m.).

Age	15		30		35	
Rootstock	Height	Area	Height	Area	Height	Area
M.IX	1·6	8·4	1·8	9·0	2·4	14·4
M.VII	2·4	19·3	2·7	18·4	3·2	24·0
M.IV	3·2	26·0	3·5	25·0	3·8	27·0
M.II	3·4	27·0	3·5	28·0	3·7	30·2
M.I	3·6	30·2	3·7	28·0	4·0	26·0
M.XVI	4·1	40·9	4·4	40·9	4·9	44·8

Accumulated crop per tree.

The relative order of rootstocks in respect of accumulated crop per tree has undergone several changes during the trial (Table IV). Trees on the dwarfing M.IX yielded the heaviest accumulated crop during the early years but these were superseded by trees on M.IV by the tenth year. By the fifteenth year, trees on M.I had

yielded the heaviest accumulated crop, and it was not until the twentieth year that the largest trees, on M.XVI, surpassed them. Hatton (1924) has reported the poorer setting of blossoms on trees on the vigorous M.I and the very vigorous M.XVI, especially during the early years, and this fact probably accounts for the relatively slow bearing of trees on these two rootstocks in this trial.

Whereas in tree size the rootstocks reached their present order by the fifteenth year, it was not until the twentieth year that the present order was established in respect of accumulated crop (Table IV). The accumulated yield of trees on the six rootstocks up to the thirty-fifth year, the size of the heaviest crop carried, and the age at which this was borne, are shown in Table VI.

TABLE VI.

Total crop in bushels (40 lb.) per tree up to 35th year and age of tree in year of heaviest crop.

Rootstock	M.IX	M.VII	M.II	M.IV	M.I	M.XVI
Total crop (bushels)	33	60	92	95	101	117
Heaviest crop (lb.)	84	166	266	263	283	409
Age of bearing heaviest crop	33	16	33	27	27	27

After the trees had settled down to bear useful crops, the rootstock seems to have had little effect upon the size of fruit with Lane's Prince Albert. Records of mean weight per fruit, as given by yearly weighings of 100 fruits over the period 1932–54, showed that trees on M.VII had produced the smallest fruits (0·309 lb.) and those on M.XVI the largest (0·339 lb.). The fruits from trees on M.VII were, nevertheless, of good market size for this culinary variety and averaged only about 12 apples to the bushel more than those on M.XVI—a negligible difference.

Fluctuation in bearing.

Factor " I " (Hoblyn *et al.*, 1936) has been calculated from the crop records (Table VII). This measures the intensity of fluctuation in bearing and is arrived at by dividing the difference in crop between consecutive pairs of years by their sum and multiplying by 100, 0 denoting equal crops harvested, and 100 no crops harvested, in alternate years.

TABLE VII.

Intensity of biennial fluctuation (" I ") in cropping, 1923–50.

Rootstock	M.IX	M.VII	M.IV	M.II	M.I	M.XVI
Mean " I "	43	45	45	46	46	50

Lane's Prince Albert is not a variety that is especially liable to bear in alternate years and generally the differences in intensity of biennial fluctuation in bearing

between trees on different rootstocks were small, but trees on M.IX were rather more regular in bearing than those on M.XVI. A poor set of fruit in 1926 and a period when severe late spring frosts were recorded, between 1935 and 1944, accounted for most of the irregular cropping.

Ratio of crop to tree weight.

The thinning of the plot, when the trees were twenty-seven years of age, enabled weight of branches and trunk to be related to area of trunk cross-section and to the total crop. The ratios of total crop to tree weight are shown in Table VIII. The order of trees on the different rootstocks is the same for area of trunk cross-section and for weight of trunk and branches though the range in the former measurement (XVI/IX=4·34) is less than in the latter (5·44). Trees on the dwarfing M.IX had yielded nearly fourteen times their own weight in fruit, whereas trees on the very vigorous M.XVI had yielded nearly five times only. No trees on M.IV were grubbed.

TABLE VIII.

Ratio of total crop to weight of trunk and branches ; trees 27 years old.

Rootstock	M.XVI	M.I	M.II	M.VII	M.IX
Number of trees	3	8	6	4	3
Area trunk cross-section (sq. cm.) ..	374	367	298	181	86
Weight of trunk and branches (lb.)	419	352	278	153	77
Ratio of total crop to tree weight ..	4·7	7·3	7·1	11·1	13·7

Crop in relation to tree size and spacing.

The total crop per unit area of trunk cross-section affords a useful measure of the relative cropping efficiency of trees on different rootstocks. This has been calculated for trees on each of the six rootstocks for three ten-year periods (Table IX), the total crop (lb.) having been divided by the area of trunk cross-section (sq. cm.) at the end of each period. The order of values for the different rootstocks is almost identical for each period. On this basis, therefore, trees on M.IX were the most efficient producers of fruit during a thirty-year period. These were followed by trees on M.VII and M.IV with little difference between them. The figures for trees on the vigorous M.II and those on the very vigorous M.XVI were very similar at both twenty and thirty years of age.

TABLE IX.

Accumulated crop per unit area of trunk cross-section in successive 10-year periods.*

1st 10-year period		2nd 10-year period		3rd 10-year period	
M.IX	6·1	M.IX	12·9	M.IX	11·4
M.VII	2·6	M.VII	8·0	M.VII	10·5
M.IV	2·4	M.IV	7·7	M.IV	10·3
M.I	2·0	M.I	5·8	M.I	8·7
M.II	2·0	M.XVI	5·3	M.II	8·0
M.XVI	1·4	M.II	5·2	M.XVI	7·8

* See text.

The different sizes of tree produced by clonal rootstocks covering a wide range of vigour affect economic distances of planting. Though few would plant an orchard of Lane's Prince Albert nowadays, this variety will serve as an example of the use of rootstocks in relation to planting distance. Planting distances for Lane's Prince Albert on different rootstocks, based upon an estimate of the present needs of each rootstock/scion combination, are shown in Table X together with estimated yields per acre as calculated from the actual accumulated yields per tree at three periods.

TABLE X.

Estimated cumulative yields per acre in bushels (40 lb.) at appropriate spacing for trees on different clonal rootstocks.

Rootstock	Distance apart in feet	Number of trees per acre	10 years		20 years		30 years	
M.IX	12	302	M.IX	1,109	M.IV	5,902	M.IV	10,968
M.VII	15	193	M.VII	1,013	M.VII	5,640	M.VII	9,539
M.IV	17	150	M.IV	956	M.IX	4,937	M.I	8,642
M.I	20	108	M.I	596	M.I	4,465	M.IX	8,229
M.II	20	108	M.II	453	M.II	3,523	M.II	7,470
M.XVI ..	24	75	M.XVI	345	M.XVI	3,133	M.XVI	6,716

This method of estimation has certain limitations—for instance it could be argued that the trees on M.IX received generous spacing throughout the trial whereas those on M.II or M.XVI were cramped, especially during the wartime period before the trees were thinned. Bearing these limitations in mind, the figures shown in Table X raise important practical considerations which will be discussed later.

TREE CONDITION AND MORTALITY.

Severe summer droughts were recorded in the twenty-eighth and thirtieth years after planting. During these and subsequent years poor foliage, dieback of shoots and spurs, and on some trees the death of whole branches, occurred. Trees on M.I were badly affected and the cutting back of those branches showing dieback affected tree spread records made at thirty-five years of age (Table V). Thus Fig. 2 gives a better comparison of the size of trees on M.IV and M.I than the tables show.

During the trial, tree mortality has been low, only four trees out of three hundred having been removed, other than those removed in thinning the plot. One tree on M.VII became infected with Apple Canker (*Nectria galligena*) at three years of age, one 25-year-old tree on M.IX was damaged by a tractor and two more trees, one on M.IV and one on M.I, were grubbed when thirty-three and thirty-four years old respectively because of infection with *Armillaria mellea*. The tree on M.I was also affected with Silver Leaf (*Stereum purpureum*).

DISCUSSION.

After thirty-five years' growth and cropping, there appears to be no falling off in shoot growth except during the period when the trees were overcrowded. The relative order for tree size on the six rootstocks was established by the fifteenth

year and that for cropping by the twentieth year. It is clear that the yielding capacity of these trees has been maintained throughout the trial ; for example, the heaviest crop from trees on the dwarfing M.IX has only recently been borne, at thirty-three years, and this crop was similar to the previous heaviest crop in the sixteenth year. Trees on the vigorous M.II also bore their heaviest crop after thirty-three years. Although trees on the semi-dwarfing M.VII bore their heaviest crop quite early, in the sixteenth year, that in the twenty-fifth year was only 10 per cent. less.

The accumulated crop per unit area of trunk cross-section, calculated at three periods during the trial, shows trees on dwarfing and semi-dwarfing rootstocks to be the most efficient producers of fruit (Table IX). The crop, calculated on an acreage basis, shows that, at the twentieth and thirtieth years, trees on rootstocks of intermediate vigour would have yielded more heavily per acre than trees on the dwarfing M.IX (Table X). Another interesting feature arises from this table when one considers the crops, on an acreage basis, in separate ten-year periods instead of accumulating the crops from each period. The crop up to the tenth year from trees on the dwarfing M.IX shows a 221 per cent. increase over that from trees on the very vigorous M.XVI. During the next ten years, this figure had been reduced to 37 per cent. During the last ten-year period, however, trees on M.XVI had not only caught up but surpassed trees on the productive M.IX by 8 per cent. It is possible, therefore, if the trial is maintained long enough, that trees on the very vigorous M.XVI may eventually out-yield those on the less vigorous rootstocks in total crop per acre. This contrast in early vigour and cropping between trees on rootstocks in widely differing vigour groups may be modified by the use of lighter pruning methods (Preston, 1954 and 1955).

Some other rootstocks in this trial are of interest since they were at one time popular and in some areas even now are widely used. Their field performance in this trial may be compared with that of more frequently used rootstocks in the appropriate vigour group. M.V, the Doucin Amélioré, was widely planted in the past but trees of Lane's Prince Albert on this rootstock are much inferior to those on M.II, which are of comparable vigour (Table I) ; similar poor behaviour of M.V has been recorded with many other scion varieties (Hatton, 1935). M.XIII, although an excellent nurseryman's rootstock, is unsuited for orchards planted on some of the dry soils of East Anglia. Trees on M.XIII in this trial have cropped, size for size, very similarly to those on Malling Crab C. This latter rootstock was received at East Malling in 1912 in a consignment of seedlings of so-called " French Crab " rootstocks from which were made five selections, lettered A, C, E, F, and H ; they were propagated vegetatively and included in the field trial. Trees of Lane's Prince Albert on Crab C are a little smaller and somewhat less productive than those on M.XVI but other scion varieties have yielded more heavily on Crab C than on M.XVI (Garner, 1946). Furthermore, this selected crab rootstock has other attributes, for example, in making a good tree on poor soils and in forming a stout trunk for cider apple varieties. Lane's Prince Albert on M.XI has made a larger tree than on M.IV but a smaller one than on M.II ; the total crop from trees on M.XI was, however, less than that from trees on M.IV and M.II by 20 and 17 per cent. respectively. In the very vigorous group, trees on M.XII were considerably larger than those on M.XVI but their total crop per tree was 21 per cent. less ; they were particularly shy in bearing during the early years, trees on M.XVI having yielded

PLATE I

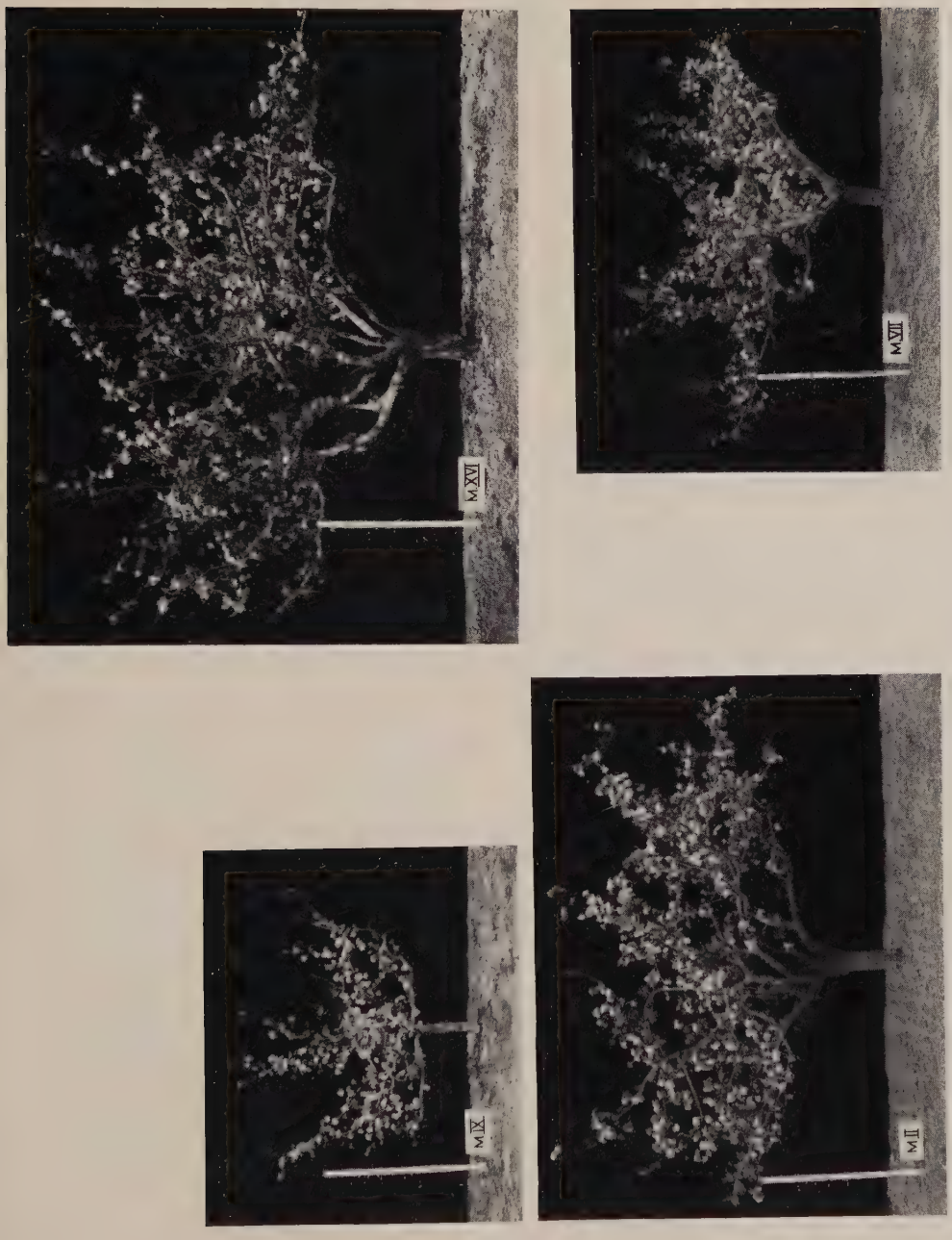

Fig. 1.
Thirty-eight-year-old trees of Lane's Prince Albert on four clonal rootstocks, M.II, M.VII, M.IX and M.XVI, showing effect on tree size.

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FIG. 2.
Thirty-eight-year-old trees of Lane's Prince Albert on three clonal rootstocks, M.I, M.IV and M.XII, showing effect on tree size.

69 per cent. more fruit by the tenth year. None of the other rootstocks included in this trial has equalled the all-round field performance of the more frequently used rootstocks, M.IX, M.VII, M.IV, M.II, M.I and M.XVI, though even these have some disadvantages, such as the poor anchorage of some scions on M.IV.

That the vigour range of these rootstocks is wide is fully established. The " Malling clones " are not all " dwarfing ", as has sometimes been assumed in the U.S.A. In fact, trees on rootstocks such as M.XVI are comparable in size with those on very vigorous seedlings, while trees on M.IX are about one-fifth of that size. Other contemporary experiments with the " Malling clones ", under many different scion varieties, have shown the relative order for vigour to hold good on a wide range of soils not only in England (Hatton, 1926 ; Rogers, 1946) but also in the U.S.A. (Sudds, 1945 ; Shaw, 1946). Nevertheless, since all soils have characteristic effects upon growth and cropping, certain rootstocks may do better on some soils than on others. This is especially true of M.I and M.II in the vigorous group, trees on M.I being intolerant of dry soils but often doing better than those on M.II on wet ones.

SUMMARY.

The growth and cropping of Lane's Prince Albert apple on 22 different clonal rootstocks, up to the age of 35 years, are reported. Trees on M.IX, M.VII, M.IV, M.II, M.I and M.XVI are dealt with in detail.

Tree size, based upon area of trunk cross-section and branch height and area of spread measurements, showed that the six rootstocks fell into five vigour groups : M.IX, dwarfing ; M.VII, semi-dwarfing ; M.IV, moderately vigorous ; M.II and M.I, vigorous ; M.XVI, very vigorous.

The relative order for tree size on the six rootstocks was established by the fifteenth year and that for cropping by the twentieth. Shoot growth decreased when the trees became overcrowded during the war period but it increased after the trees were thinned.

Trees on the dwarfing M.IX yielded the heaviest accumulated crop per tree during the early years, but they were superseded by trees on the moderately vigorous M.IV by the tenth year. By the fifteenth year, trees on the vigorous M.I had yielded the heaviest accumulated crop and it was not until the twentieth year that these were surpassed in cropping by the largest trees, viz. those on the very vigorous M.XVI. The heaviest annual yield was recorded at thirty-three years of age for trees on M.IX and M.II and at twenty-seven years for trees on M.IV, M.I and M.XVI. Trees on M.VII yielded their heaviest crop at sixteen years of age.

The yields are discussed in relation to tree size and spacing. On an acreage basis the small trees on M.IX, at 12 feet apart, had much heavier estimated yields than the large trees on M.XVI, at 24 feet apart, during the first two ten-year periods. During the last ten-year period, however, the reverse was the case.

Regularity in bearing was affected by late spring frosts in some years. Trees on M.IX were the most regular in bearing and trees on M.XVI the least regular ; there was little difference between trees on the other rootstocks.

Tree weights, obtained from trees grubbed at twenty-seven years of age, showed that those on M.IX had by then yielded 14 times their own weight in fruit and trees on M.XVI 5 times their own weight.

The growth and cropping of trees on some other rootstocks that have been used in certain fruit-growing areas are compared with those of trees on more frequently

used rootstocks in the appropriate vigour group. Trees on the remaining rootstocks in the trial failed to equal the all-round performance of those on the six selected rootstocks that are dealt with in detail.

ACKNOWLEDGMENTS.

These studies were initiated by Sir Ronald Hatton who was assisted by the late Mr. Jesse Amos until 1945. Mr. T. N. Hoblyn was responsible for many of the earlier calculations and his long experience has been very valuable to the author. Many past and present members of the Pomology and Statistics Sections have assisted in securing and summarizing data, and two recorders, Miss E. C. M. Ashdown and Miss F. M. Hodges, have been associated with this work for more than twenty years. Dr. A. F. Posnette and Mr. R. Cropley carried out the virus tests. The help of all these and many others is gratefully acknowledged.

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(*Received* 7/3/57.)

A BOLTING-RESISTANT STRAIN OF DETROIT BEET

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DETROIT Dark Red is the leading variety of round beet in use in Britain. It was introduced into the U.S.A. in 1892 by D. M. Ferry and Co. of Detroit. Their stock was derived from selections of the European variety Early Blood Turnip (Vilmorin) previously made in Canada by Reeves of Port Hope.

Although fine stocks of Detroit Dark Red are now available, showing great regularity in shape and colour, and the variety is widely grown for early production in conditions that encourage bolting, little success has been achieved in breeding for bolting in spite of the fact that the technique of improvement has been known for many years.

A posthumous paper by Bateson, prepared for publication by Hall (2) in 1925, describes work on the inheritance of the bolting habit in cultivated forms of *Beta maritima*. He showed that the ordinary stocks of mangolds, sugar beet and garden beet constituted mixed populations mainly biennial in habit but containing a proportion of individuals which would bolt under normal sowing conditions. This proportion would rise rapidly under conditions favourable to bolting, e.g. early sowing. Though bolting was markedly affected by environment, individuals differed in their resistance to conditions that encourage bolting. These differences were shown to be genetic in origin and were inherited. Thus commercial stocks of mangolds, sugar beet and garden beet could easily be freed from strains showing liability to bolting under normal conditions of growth. Bateson had previously described the object of his experiment to a meeting of the Agricultural Section of the British Association in 1911. He said, " I think it is not impossible that the bolters can be wholly, or almost wholly, eliminated by the application of proper breeding methods."

In order to flower, beet requires a period of low temperature acting on the growing point, followed by a long photoperiod acting on the leaves. Bell and Bauer (1), working on sugar beet, showed that low temperature and continuous light treatment of seedlings were effective in the process of isolating bolting-resistant types. Low temperature treatment (1° C.) of seedlings was found to have morphological effects on early growth similar to those obtained from 24-hour illumination.

In 1954 Wellensiek and Verkerk (3) demonstrated that flowering of red garden beet could be encouraged by extending the photoperiod to 24 hours by artificial light and that the natural cold which affected plants sown in cold frames in the second or third week in January had a stronger flower-promoting effect than artificial vernalization of seed at 1° C. for six weeks.

The effect of natural cold on round beet seedlings is well known to growers of this crop for the early market. The sowing of main crop beet is usually delayed until May but the grower of early crops will risk a sowing in April or even at the end of

March. These early sowings naturally produce a high proportion of bolters and March-sown crops, because of the very low temperatures to which the seedlings may be subjected coupled with exposure to the long days of May and June, are often a complete failure through excessive bolting.

Experimental results.

In 1948 at Wye College a programme of selection was initiated with the object of producing a strain of round beet which could be sown in March for the early market without producing too high a proportion of bolters. It was clear that this object could be attained by sowing succeeding generations in mid-March, the time when the improved strain might be expected to be sown by market growers, and by roguing the bolters. This method of selection would make use of no artificially produced conditions to induce bolting and, if successful, it should produce a strain suited to the environmental conditions in which it would eventually be grown. The course of the selection over the nine years 1948–1956 was as follows :

In 1948 about $\frac{1}{8}$ acre of a commercial sample of Detroit Dark Red was sown on 20th March and was given normal commercial treatment throughout the season. By mid-September, 15 plants remained unbolted. These were lifted and stored and in the following year were grown on for seed. In 1950 seed from the 15 unbolted plants was sown on 20th March and unbolted plants stored in September. A seed crop was grown from these roots in 1951.

On 17th March 1952 two plots were sown ; one with the original and one with the improved stock. After sowing, ten ground frosts were recorded (maximum, 7° F. of frost), two in March, seven in April and one in May. In spite of the relatively mild conditions prevailing during the spring, on 7th July 62 per cent. of the original stock had bolted as compared with 5·7 per cent. of the improved strain.

Up to this point little attention had been paid to selection for type and quality except that in 1950 obviously rough roots had been discarded. At the 1952 selection, however, all unbolted plants which did not conform in shape to the original stock were rejected. The remaining roots were cut longitudinally into 4 pieces and further plants were rejected as failing to conform to the standards of colour and tenderness of the original stock. The 30 quartered roots remaining were immediately replanted and were lifted and stored in September.

Seed from the selected roots was produced in 1953. In 1954 a further selection was made and in the following year a seed crop was produced from the selected roots. In 1956 a comparative trial was undertaken. On 21st March 10 plots were sown each containing one row of the improved and one row of the original stock. The rows were eventually thinned to about 40 plants each, the two rows in each plot always containing the same number of plants.

Germination started on 10th April and thereafter the seedlings were exposed to more rigorous climatic conditions than had previously been experienced in the course of the selection work. No frosts were experienced in March but in April the grass minimum temperature fell below 30° F. on 15 occasions and temperatures as low as 21° F. were recorded. Night ground temperatures remained low throughout May. During March, April and May, very dry conditions prevailed, the rainfall being 0·90 in., 0·75 in. and 0·70 in. in successive months. Such prolonged drought might be considered to be another environmental factor encouraging bolting.

Recording of the trial plots took place on 14th June, 13th July and 18th July (Table I). Slight bolting had been noted in the original stock on 4th June and

TABLE I.

Percentage of bolters in original and improved stock.

Plot	Sampling dates, 1956					
	14th June		13th July		18th July	
	Wye strain	Original strain	Wye strain	Original strain	Wye strain	Original strain
1	0	21·0	7·9	76·3	21·0	76·3
2	0	18·6	23·3	83·7	27·9	88·4
3	2·3	32·6	25·6	79·1	27·9	81·4
4	0	23·3	20·9	65·1	27·9	74·4
5	0	24·4	28·9	82·2	51·1	84·4
6	0	13·2	15·8	76·3	31·6	86·8
7	0	27·9	25·6	81·4	55·8	86·0
8	5·1	33·3	35·9	79·5	35·9	84·6
9	0	23·1	20·5	84·6	30·8	94·9
10	0	16·7	9·5	69·0	23·8	83·3
Weighted mean ..	*0·73*	*23·4*	*21·55*	*77·96*	*33·65*	*84·01*
Statistical significance	P<0·001		P<0·001		P<0·001	

by 14th June the proportion had increased to 23·4 per cent. In the improved strain less than 1 per cent. of bolters was recorded. At this time the roots averaged ½ in.–1 in. in diameter. About 10 days later (24th June) the beet was fit for sale but no further recording could be made until 13th July when the roots would be considered rather large for marketing as early salad beet (see weights in Table II).

TABLE II.

Average weight (gm.) of an unbolted beet on 18th July, 1956.

Plot	1	2	3	4	5	6	7	8	9	10	*Av. of all plots*
Wye strain	303	221	200	228	236	200	191	224	213	184	*220·0*
Original strain ..	225	150	163	235	179	133	160	125	150	221	*174·1*

Wye strain>original strain (P<0·01).

At this stage the proportion of bolters had increased to 21·55 per cent. in the improved strain and to 77·96 per cent. in the original. In these recordings beet were considered to have bolted if the slightest trace of a flower spike could be seen when

the growing tip was carefully examined. Some indication of the difference in degree of bolting in the two stocks is provided by the figures in Table III.

TABLE III.

Average height (cm.) of bolters on 13th July, 1956.

Plot	1	2	3	4	5	6	7	8	9	10	*Av. of all plots*
Wye strain ..	0	30·2	25·0	21·0	23·2	17·5	22·2	32·1	17·2	11·2	*20·0*
Original strain	44·5	52·5	56·0	55·6	50·0	44·7	49·2	59·7	50·5	38·7	*50·1*

Wye strain<original strain ($P<0.001$).

The lifting of the beet for further selection took place on 18th July when a final recording was made. By that time 33·6 per cent. of the improved strain and 84 per cent. of the original had bolted. Thus, under the severe conditions prevailing at Wye in 1956, the new strain showed a very marked improvement. No other differences could be detected, leaf colour, shape and skin texture remaining unchanged.

Too much reliance cannot be placed on the average weights shown in Table II as very few beet remained unbolted in the plots of the original stock and these tended to be below average size. It seems clear, however, that the vigour of the new strain is not less than that of the original. Seed-producing power and seed germination also appear to have been unimpaired by the selection.

The National Institute of Agricultural Botany has accepted this stock for further testing. If the tests are passed it will be certified and distributed under the name of Detroit, Wye Cardinal strain.

SUMMARY.

A commercial stock of Detroit Dark Red beet was selected in the field for reduction in bolting. Over the period 1948–1955 four generations of seed were so treated, the last two of which were also selected for quality (shape, colour, tenderness of flesh). In 1956, a season which was highly favourable to bolting in early beet crops, the percentage of bolters in the improved strain at maturity was only about one-quarter of that shown by the commercial strain and this advantage was obtained without loss in yield of the non-bolted plants.

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(*Received* 22/3/57.)

OBSERVATIONS ON GROWTH TRENDS OF THE TOMATO PLANT THROUGHOUT THE WHOLE OF THE GROWING SEASON

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THE tomato is the major glasshouse crop in the United Kingdom and much applied experimental work has been carried out on it. It is, therefore, rather surprising that no quantitative analysis of the growth of the tomato plant in the environment of a commercial-type glasshouse throughout the whole of a growing season appears to have been made, since the assessment of growth is a logical prerequisite to the planning of experimental work by which it is intended to modify it. The present account deals with three years' observations on the growth of the different organs during 1954–56, the first year at the Cheshunt Experiment Station in the Lea Valley and the other two at the Glasshouse Crops Research Institute in the Worthing area.

Technique.

In all three years the variety used was Potentate and all the axillary shoots on the main stems of two plants were allowed to develop, the second order axillary shoots being removed as soon as they appeared. It was not possible to use more than two plants as considerable labour was needed to record the growth of the large number of axillary shoots that developed. No leaf was removed from either the main stems or the axillary shoots until the major part of the lamina had lost its green colour and was largely dry and brown. Measurements were made at weekly intervals of the lengths of the leaves from the axil to the tip, the lengths of the axillary shoots from the junction with the main stem to the growing point, and the diameters of the fruits. These diameter measurements were converted to the cubes of the radii as estimates of fruit volume.

The first year's observations differed from those of the succeeding two years in that they included weekly measurements of the length of the roots visible in the glass-lined side of a trench. This glass panel was 2 ft. 8 in. deep and 4 ft. wide and the plants were sited 13½ in. distant from the panel. The first year's observations were discontinued at the beginning of July, as by this date the plants had reached the roof of the aeroplane-type glasshouse. In the second and third years the work was carried out in a taller vinery-type house. During these years, observations on the growth of the roots were not made and the plants were grown 6 ft. apart, to reduce the competition between them and to facilitate the collection of the data.

A further difference was that in the first year the plants were grown in an old glasshouse border that had been steamed after the previous crop, whereas during the last two years they were grown in new glasshouse soil that had never been steamed. The soil structure and the soil profile were also very different at the two sites.

The seed was sown on 13th January 1954, 21st December 1954 and 22nd November 1955.

Pattern of development of axillary shoots.

In Fig. 1 are shown the final lengths attained by the axillary shoots of one of the plants in each of the three years. The lengths of the axillary shoots are indicated

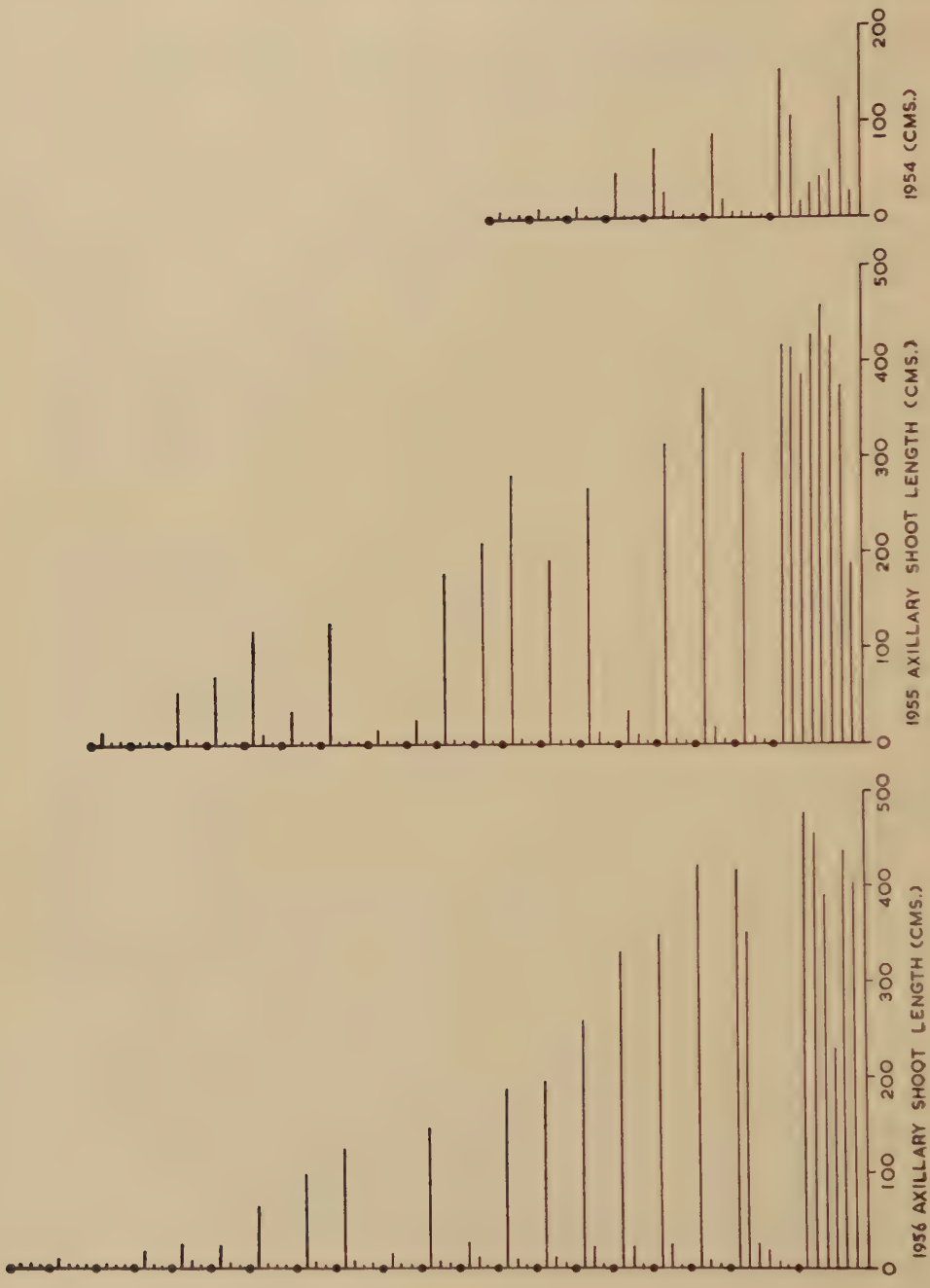

FIG. 1.
Pattern of axillary shoot growth, 1954–1956.

by horizontal lines and the positions of the flower trusses on the main stem are shown by solid circles.

There was a similar regularly recurring pattern of axillary shoot growth in each year. This pattern was related to the position of the flower trusses on the main stem, the most vigorous shoots being those that arose in the axils of leaves immediately below trusses. The growth of shoots arising in the axils of leaves immediately above trusses was practically inhibited, while intermediate axillary shoots exhibited intermediate degrees of vigour. The vigour of growth of all the axillary shoots arising below the first truss (i.e. not only the shoot immediately below the first truss but those arising lower down on the main stem as well) was similar to that of an axillary shoot arising immediately below a truss.

In 1954, because of the low glasshouse, the work had to be discontinued before the fruit ripened, but the pattern of fruit production in 1955 and 1956 was similar to that of axillary shoot extension growth, since, almost without exception, the shoots that bore fruit were those below the first truss and those arising immediately below the successive trusses on the main stem. The correlation coefficient for axillary shoot length and the weight of fruit borne by the axillary shoots was +0·94 in 1955 and +0·92 in 1956. These were both significant at the 0·01 level of probability.

Time relationships in the growth of the shoots, leaves, roots and fruit.

The mean weekly absolute rate of shoot extension growth of the main stems and axillary shoots of the two plants in each of the three years is shown in Fig. 2. The

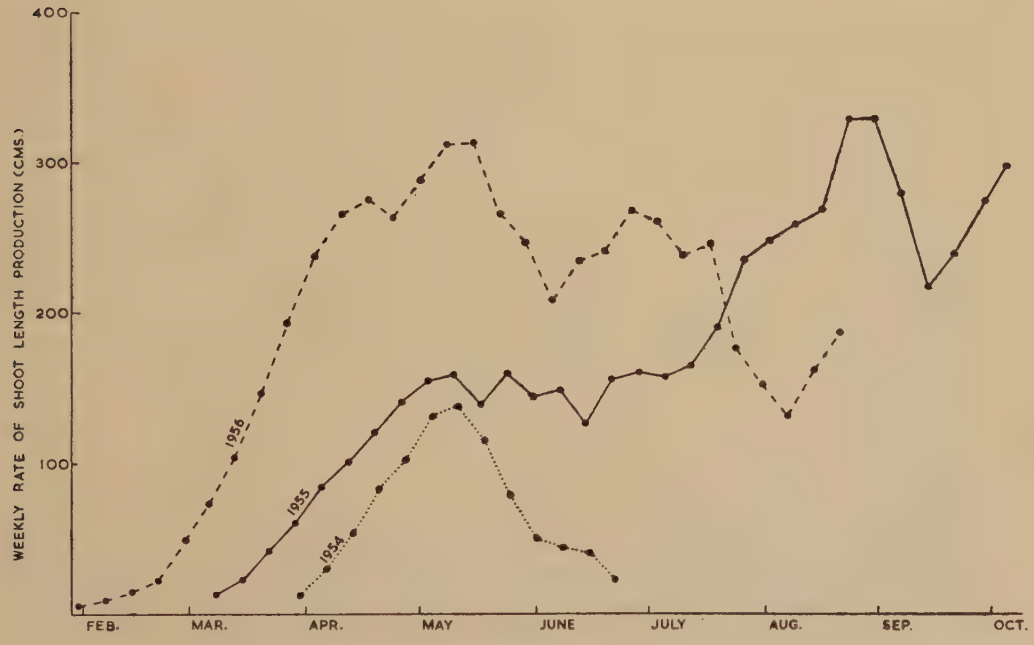

Fig. 2.
Shoot extension growth, 1954–1956.

points plotted are the moving averages based on three weeks' data, i.e. any point is influenced by both the preceding and succeeding week's data.

It can be seen that the weekly rate of shoot extension growth in all three years increased steadily until early May when a check occurred.

To present data on leaf development comparable with those on shoot growth, the mean weekly rate of leaf length production on the two plants in each of the three years was calculated. The rate in any one week was obtained from the equation:

$$P = (a_2+b_2)-(a_1+b_1)$$

where P = the weekly rate of leaf growth
a = leaf length present on plant
b = accumulated total of leaf length removed
1 = first week under consideration
2 = second week under consideration.

The leaf length data during the first year were recorded in such a form that it was not possible to calculate the rate of leaf growth in this way, and consequently Fig. 3 gives data for two years only. The points plotted are again the moving averages based on three weeks' data.

It can be seen from Fig. 3 that leaf growth was checked in both years in early May, i.e. at approximately the same time as the check to shoot extension growth.

That in 1954 the development of the root system was similarly checked in early May is also apparent from Fig. 3, where the weekly rate of root extension growth visible in the glass panel is plotted. A moving average has not been used to bring out the trend since the individual observations (connected by the dotted line) show

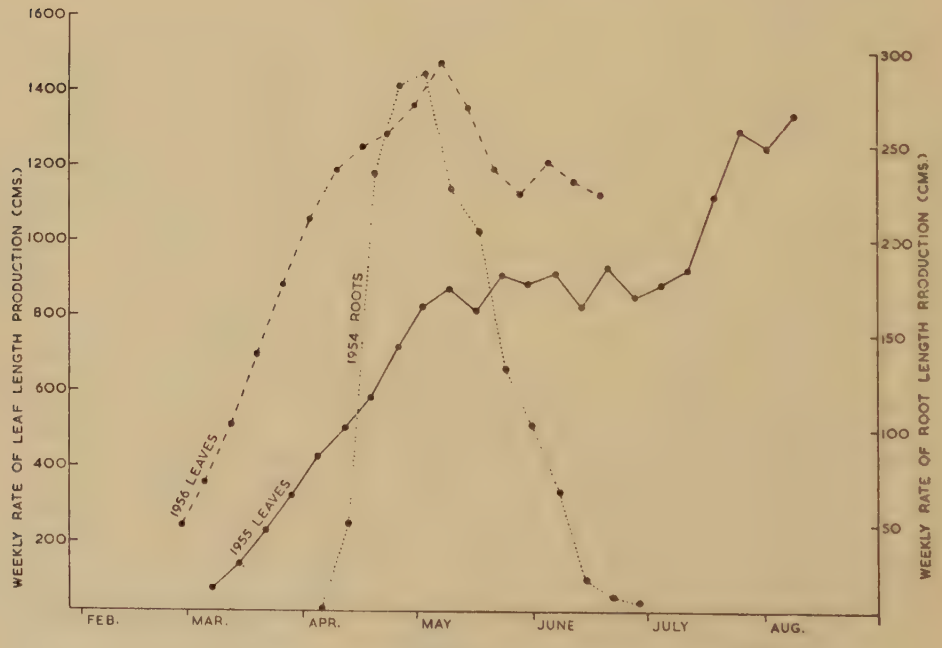

Fig. 3.
Leaf growth, 1955 and 1956 ; root growth, 1954.

a pronounced trend. The time of occurrence of this check is in agreement with the findings of Leonard (1952, 1954) who reported a check between late April and early May in the development of the root system of the tomato.

The formula used for calculating leaf growth data was also used to obtain comparable data on fruit development, P now representing the weekly rate of fruit swelling in cubic centimetres ; a, the fruit volume on the plant and b, the accumulated total of fruit volume picked.

Picking had not begun in 1954 by the time that the observations were discontinued so, for that year, the fruit volume produced was the same as that present on the plant. The volume of fruit in 1954 was small relative to that in each of the following two years ; in Fig. 4 the data for 1954 have therefore been multiplied by 10 to magnify the trend.

It can be seen from Fig. 4 that the steadily increasing rate of fruit swelling was checked between mid-May and mid-June in each of the three years, i.e. some weeks after the check to shoot growth.

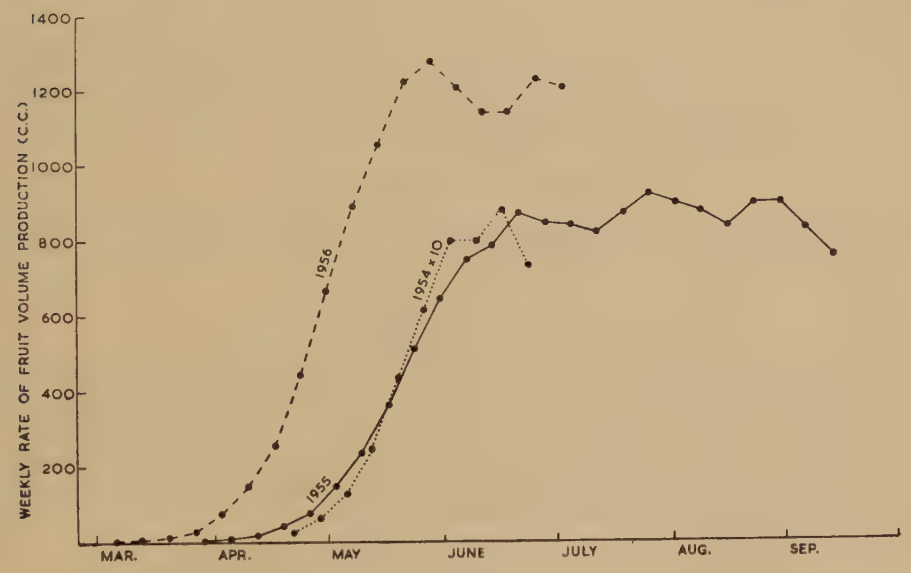

Fig. 4.
Fruit development, 1954–1956.

The conclusion can thus be drawn that in the variety Potentate the growth of roots, shoots and leaves was checked at about the same time in early May, and approximately four weeks later the growth of the fruit was similarly checked. This happened at the same time in each year irrespective of the different stages of development of the plants resulting from the differences in sowing dates in the three years, and irrespective of the differences in soil conditions at the two research stations and the differences in cultural practice.

The factor controlling the development of the organs.

The fact that the maximal rate of development of the organs was reached at approximately the same time each year, irrespective of the age of the plant or the cultural conditions under which it was grown, suggested that the major controlling factor is not among those that determine short term fluctuations or that vary erratically from year to year in a glasshouse, i.e. it was unlikely to be air temperature, light intensity, soil moisture or the nutrient supply in the soil. Nor, since variation of the date of sowing over a range of 7–8 weeks had little effect, is the relative stage of development of the four organs—shoot, leaves, root, fruit—likely to be the major controlling factor. The controlling factor would appear to be one that is dependent on the advance of the season.

SUMMARY.

1. Three years' observations have shown that there is a regularly recurring pattern of axillary shoot extension growth and fruit production in the Potentate variety of tomato. This pattern is related to the position of the flower trusses on the main stem.

2. A check to the steadily increasing rate of development of the roots, shoots and leaves occurs approximately in early May. A few weeks later a check to the increasing rate of development of the fruit occurs. This appears to be independent of the age of the plant and of its cultural management.

ACKNOWLEDGMENTS.

The writer wishes to acknowledge the collaboration of Dr. E. R. Leonard in this work.

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(*Received* 28/3/57.)

THE EFFECT OF ORCHARD FACTORS ON THE CHEMICAL COMPOSITION OF APPLES

II. THE RELATIONSHIP BETWEEN POTASSIUM AND TITRATABLE ACIDITY, AND BETWEEN POTASSIUM AND MAGNESIUM, IN THE FRUIT

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SYNOPSIS.

The free acid in apples and the main alkaline constituent (potassium) are known to vary within wide limits and yet the pH of the fruit remains fairly constant and is characteristic for the variety. It has therefore been suggested that anything causing an increase in potassium content (such as application of potash or the type of season) must also result in a corresponding increase in acidity. This paper describes experimental results from manurial and management trials which confirm that this expected relationship exists. Deviations from the theoretical are discussed.

The results from the same trials also suggest that increased potassium in the fruit is accompanied by increased magnesium. This result is contrary to that found for leaves where higher potassium means lower magnesium, even to the extent of magnesium deficiency ; it is therefore suggested that high potassium fruits may draw magnesium from the leaves.

In a previous paper (Wilkinson, 1957) figures were given for the chemical composition of Cox's Orange Pippin apples from a manurial trial, and the effects of treatment and of season were discussed. In the present paper the interrelationships between some of the constituents are considered.

POTASSIUM AND TITRATABLE ACIDITY.

It is generally recognized that the water phase of the apple approximates to a strong base/weak acid buffer system, in which the acid is mainly malic and the base is mainly potassium. The acid is only partially neutralized and the pH of the fruit is usually less than 4. For comparison, a potassium hydroxide/malic acid mixture has a pH of 4 when about 50 per cent. of the acid is unneutralized. A pH of 3 is shown by a mixture in which there is about 85 per cent. of unneutralized acid. Between these limits the percentage neutralization/pH curve is almost linear, so that a rise of 0·1 in the pH value corresponds to a decrease of 3·5 per cent. in the proportion of unneutralized acid.

Haynes and Brown (1928) suggested that, since the potassium component did not vary much (being usually about 90 per cent. of the total base), the potassium content of the apple could be calculated from the simple estimations of pH and titratable acidity of the juice. For Bramley's Seedling and Lane's Prince Albert they compared calculated values with those obtained by analysis and found reasonable agreement.

It follows from this simplified picture that, for similar pH values, the titratable acidity should be proportional to the potassium concentration.

Indirect evidence of a relationship between potassium and acid has been provided by reports of correlations between fruit acidity and leaf potassium, and between

fruit acidity and potash applied to the soil (e.g. Eaves and Leefe, 1955), but there does not appear to be any evidence from comparisons of potassium and acid in the same tissue. The figures referred to at the beginning of this paper permit this comparison to be made. Some measurements of Laxton's Superb are also available.

Material and methods. The Cox's samples were taken from two seasons' crops from an East Malling manurial trial, there being four trees each of 16 treatments embracing all possible combinations of N, P, and K fertilizers with both grass and clean cultivation. A full description has been given earlier (Wilkinson, 1957).

The samples from each tree consisted of 25 apples, frozen and ground complete except for the seeds. In 1954 samples from all 64 trees were analysed, but in 1955 the total of 100 apples from the four trees comprising any one treatment were mixed together. Thus for 1954 figures are available for individual trees, whereas in 1955 they refer only to averages per treatment.

The Laxton's Superb were taken from an East Malling soil management trial. There were six treatments which it is not necessary to describe here. Each sample for analysis came from two trees.

The methods of chemical estimation have already been described (Wilkinson, 1957). pH was measured before titration and at a temperature of 15° C. A glass electrode was used.

Results.

The average values of potassium and of titratable acidity for Cox's Orange Pippin apples from the various treatments were contained in Tables I and II of the previous paper. As a test of whether they are related, and for convenience of discussion, they have been plotted against each other (Fig. 1), but before discussing the results it is necessary to examine the limitations of this approach.

1. Ideally there should be only two variables, potassium and acid. This is obviously unattainable but, in the samples chosen, variations in locality, climate, rootstock and age of tree have been excluded and subsoil variations have been minimized by the statistical layout of the trees. The principal variables remaining are manurial treatment and management, both of which are likely to have an effect on the potassium content.

2. pH should also be excluded as a variable because a change in pH involves a change in degree of neutralization. The pH's of the apples in the manurial trial are given in Table I.

Table I.

pH of Cox's Orange Pippin apples at time of gathering, under different manurial treatments, 1954 and 1955.

Orchard management		Manurial treatment							
		NPK	NP	NK	PK	N	P	K	Nil
Cultivation	1954	3·61	3·53	3·50	3·61	3·58	3·47	3·66	3·55
	1955	3·43	3·38	3·39	3·40	3·40	3·36	3·39	3·37
Grass	1954	3·53	3·51	3·55	3·50	3·51	3·53	3·52	3·48
	1955	3·37	3·36	3·37	3·37	3·37	3·37	3·37	3·38

There was a pH range of 0·19 in 1954 and 0·07 in 1955. The 1954 range can be expressed as a plus or minus shift of about 2·5 per cent. in the proportion of unneutralized acid. For that year, half the readings fell within a range of 0·04, and in 1955 half fell within a range of 0·02. Therefore, taking into account possible experimental error and the limits of a glass electrode, the pH's can be said to lie within a fairly narrow range.

3. It is necessary to know what proportion of the total cation concentration is represented by potassium and whether this proportion remains constant. In the original data for Cox's, figures were given for the three major bases, potassium,

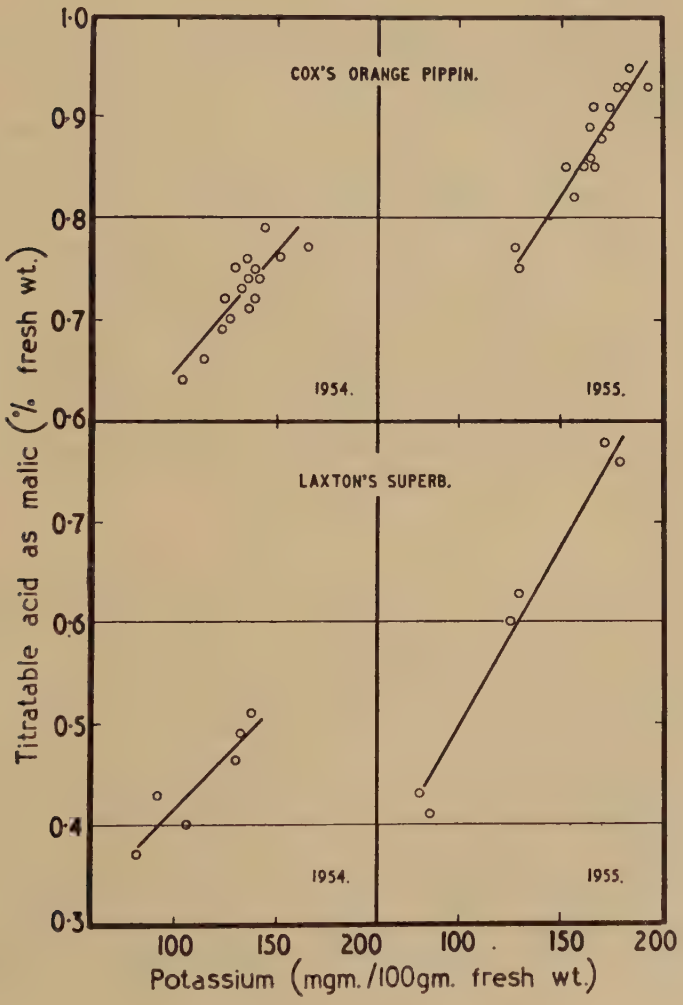

FIG. 1.

Relationship between titratable acid and potassium in the fruit.

magnesium, and calcium. If these figures are recalculated as equivalents, it is found that, for the sixteen treatments of the manurial trial, the proportion varied from 79 to 84 per cent. in 1954 and from 83 to 87 per cent. in 1955. The potassium in the Laxton's ranged from 80 to 87 per cent. of the total base. The inclusion of sodium (say, 3 mg./100 gm. fresh weight) has the effect of reducing these figures by about 3 per cent. Potassium therefore accounts for about 80 per cent. of the total.

Whilst all the potassium in an apple appears to be in the water phase, it is not known what proportions of calcium and magnesium occur in the sap. Some of the calcium is bound as pectate in the cell walls and it may be that calcium plays little part in the buffer system. The distribution of magnesium in the cell is also uncertain. The figures given above for the proportion of potassium to total base are thus lower limits, and it is considered legitimate to use potassium concentration as an index of the total cation concentration. Variation from sample to sample may however result in some scatter of points on the potassium/acid diagrams.

With the above limitations in mind, it appears from Fig. 1 that, over the ranges shown, the relationship is substantially linear. Calculated lines of best fit have been superimposed. A rise in acid of about 0·1 per cent. fresh weight is associated with a rise of 30 to 40 mg. of potassium per 100 gm. fresh weight.

Taking the values for all 64 trees in 1954—the complete figures have not been given—the correlation between potassium and titratable acidity was highly significant ($r=+0·78$). The figures were also analysed to exclude treatment effects and the resulting correlation within treatments was also highly significant ($r=+0·53$).

In Fig. 1 are also plotted the results for Laxton's Superb for 1954 and 1955, and these show the same general relationship between potassium and acid. There was rather more variation in pH for Laxton's than for the Cox's but not sufficient to obscure the general trend. The actual figures are set out in Table II. The magnesium values will be referred to later.

TABLE II.

Titratable acidity and concentration (mg./100 gm. F.W.) of potassium and magnesium in Laxton's Superb apples, 1954 and 1955.

Treatment code	1954				1955			
	Titratable acid as malic (% F.W.)	Potassium	Magnesium	pH	Titratable acid as malic (% F.W.)	Potassium	Magnesium	pH
GN ..	0·40	106	4·0	3·65	0·60	125	5·3	3·36
G2N ..	0·46	130	4·1	3·71	0·63	129	5·3	3·34
SN ..	0·49	132	4·1	3·67	0·76	179	6·6	3·50
S2N ..	0·51	137	4·2	3·66	0·78	173	6·0	3·47
CN ..	0·37	81	2·9	3·56	0·43	80	3·0	3·46
C2N ..	0·43	91	2·9	3·57	0·41	76	3·4	3·43

Further evidence of the relationship between potassium, acid, and pH can be provided from some estimations on samples of apples taken at different stages of development. The measurements so far discussed have all been made at the picking date. Table III gives some figures for Cox's from an East Malling orchard picked more than three months early, and then at fortnightly intervals. As before, the results are for samples of 25 apples, frozen and ground together.

In this table, pH's have been derived from the figures for potassium and acid (by reference to a pH/percentage neutralization curve), and are compared with the observed values. Potassium has again been assumed to be 80 per cent. of the total cation.

TABLE III.

Relation between titratable acidity, potassium content and pH for Cox's Orange Pippin apples at various stages of development.

Weeks before normal picking date	Average apple weight (gm.)	Titratable acid as malic (% F.W.)	Potassium (mg./100 gm. F.W.)	Percentage neutralization	pH derived from neutralization curve	Observed pH
15	4·7	1·17	202	27·1	3·31	3·10
13	14·5	1·32	156	20·2	3·13	3·13
11	24·5	1·20	136	19·6	3·10	3·14
9	40·2	1·17	151	21·7	3·16	3·14
7	61·8	1·12	134	20·5	3·13	3·13
5	85·0	1·12	154	22·8	3·20	3·20
3	96·2	1·00	138	22·8	3·20	3·20
1	97·8	0·90	132	24·0	3·23	3·24

The agreement is close, except for the first sample when the apples were very small.

The figures also provide evidence that the proportion of potassium to total cation remains constant for most of the time during which the fruit is increasing in size.

It is concluded from these observations that there is a close connection between potassium and acid, and that potassium plays a major rôle in the maintenance of the narrow range of pH characteristic of the variety. From this it can be argued that either (1) potassium is absorbed by the apple in the amounts necessary to form the required buffer with the existing acid, or that (2) the pH is maintained by the formation of the requisite amount of acid to balance already existing potassium. This second argument has been advanced by Tomkins (1954), who also discussed the possible effects of different levels of available carbohydrate on acid formation and pH. It is an argument which may be supported by the fact that addition of potash to the soil leads to an increase in potassium concentration in the apple. If this is a direct effect then the increase in acid formation must be secondary.

The relationship is also influenced by season. The lines of best fit in Fig. 1 are not part of a common line. There is a similarity between the slopes of the lines in the same season, but a difference between seasons. Tables I and II also show

that the average pH values were higher in 1954 than in 1955. In Fig. 2, the lines from Fig. 1 have been superimposed on theoretical lines of acid against potassium, calculated for different pH's (potassium has again been assumed to be 80 per cent. of the total cation). The lines of best fit are less steep than the theoretical lines, and taking the 1955 Cox's as an example, the actual acid in the sample with the highest potassium content is 15 per cent. lower than might be expected from the theoretical line of constant pH passing through the lowest point.

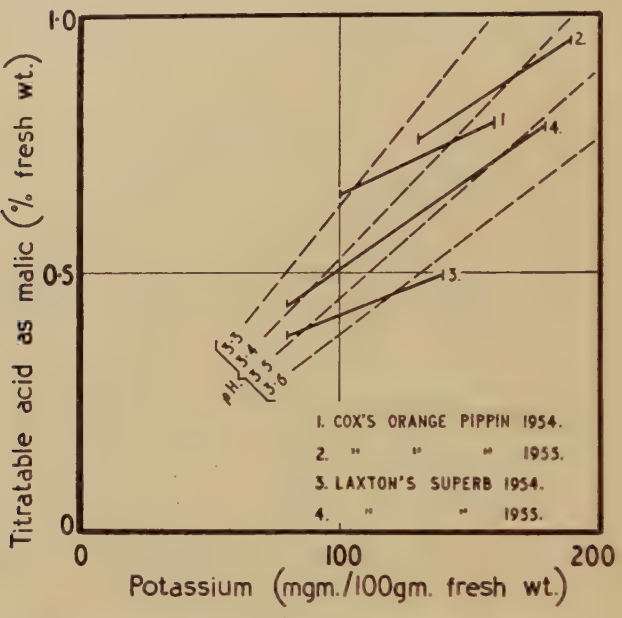

FIG. 2.

Lines of best fit from Fig. 1 superimposed on calculated lines for a range of pH values.

The slope of the lines could be modified in two ways. Firstly, the proportion of potassium to total cation might be greater at higher potassium concentrations, with the result that lower acid is required to give the same pH. It can be shown that, to account for a 15 per cent. fall in acid at the upper end of the curve (Cox's, 1955), the potassium would have to vary from 80 per cent. of the total cation at the lowest point to 93 per cent. at the highest. The analysis figures do not support such a large variation; the maximum possible range, assuming all the potassium, magnesium, calcium and sodium to be in the water phase, was 76 to 81 per cent. If a large part of the calcium occurs as pectate then the range is considerably less. Variation in potassium proportion can thus only partially explain the angle of the curves.

The second possibility is that the pH increases from samples of low potassium content to those of high. It can be seen from the constant pH lines that a drift of about 0·1 of a pH unit would account for the variations in slope. In the actual pH measurements there is a suggestion of a drift in 1954 Laxton's Superb (Table II). That there is an effect of pH on the slope of the lines for Cox's can be shown by

allowing for pH in the calculation of the regression coefficients of acid on potassium. The regression coefficients of the lines in Fig. 1 are 0·00234 (1954) and 0·00304 (1955). Allowing for pH, these become 0·00267 and 0·00341 respectively. This effect of pH, although in the right direction, is not in itself sufficient to account for the departures from the theoretical lines in Fig. 2—the regression of the line marked pH 3·4 is about 0·005. Thus although both pH and proportion of potassium to total cation have probably modified the slopes of the lines, it is possible that some additional factor is also operating.

On the supposition that potassium content determines acid level, four limiting conditions can be visualized, depending upon how the weather affects, perhaps separately, potassium supply and acid formation :

1. Low potassium and correspondingly low but adequate acid. Constant pH.
2. Low potassium and " lagging " acid with the pH increasing at the higher potassium values (the 1954 lines for both varieties in Fig. 2 might be of this type).
3. High potassium and adequate acid giving a fixed pH for all values.
4. High potassium and " lagging " acid, with pH increasing at higher concentrations.

For a complete understanding of the connection between acid and potassium, a closer examination of individual apples and of portions of apples may be necessary, together with a knowledge of the movement of these substances in adjacent tissues.

POTASSIUM AND MAGNESIUM.

The same samples of apples show a parallelism between potassium and magnesium concentrations. In Fig. 3, magnesium has been plotted against potassium for the sixteen manurial treatments of Cox's and for the six treatments of Laxton's Superb, each for two seasons, and it will be seen that samples of high potassium content tend to have high magnesium, and vice versa. There are approximately ten equivalents of potassium in the fruit to one of magnesium, and this over a more than two-fold range of concentration.

This trend is of interest because it is well known that magnesium deficiency symptoms in the tree can be induced by heavy application of potash (Wallace, 1939), an effect which has sometimes been attributed to antagonism between potassium and magnesium at the root surface. Moreover, inverse relationships between potassium and magnesium have been reported for leaves (Gruppe, 1955). Fudge (1939) however has shown that in grapefruit the fruit may draw magnesium from the leaves, which may then show deficiency symptoms. It is possible that a similar movement of magnesium from apple leaves into the developing fruit may also induce deficiency, especially under conditions of high soil potash and marginal magnesium supply.

It is significant in this respect that deficiency symptoms are more marked towards the end of the growing season and may be more severe in a heavily cropping tree (Wallace, 1951).

An attempt may be made to calculate the amounts of magnesium involved by considering some of the figures for apple trees given by Van Slyke (1932). His suggested amounts per acre were 300 bushels of fruit (i.e. 12,000 lb.) and 1,000 lb. of leaves. He also gave the weights of magnesium in 1,000 lb. of dry matter as 0·6 lb.

for fruit and 6·3 lb. for leaves. If it is assumed that there is 20 per cent. of dry matter in the fruit and 40 per cent. in the leaf, then the distribution of magnesium per acre would be 1·44 lb. in the fruit and 2·52 lb. in the leaves. The total amounts of magnesium in fruit and leaf may therefore be of the same order, and an increase of, say, 50 per cent. in the amount of magnesium in the fruit could have a substantial effect on the magnesium content of the leaves.

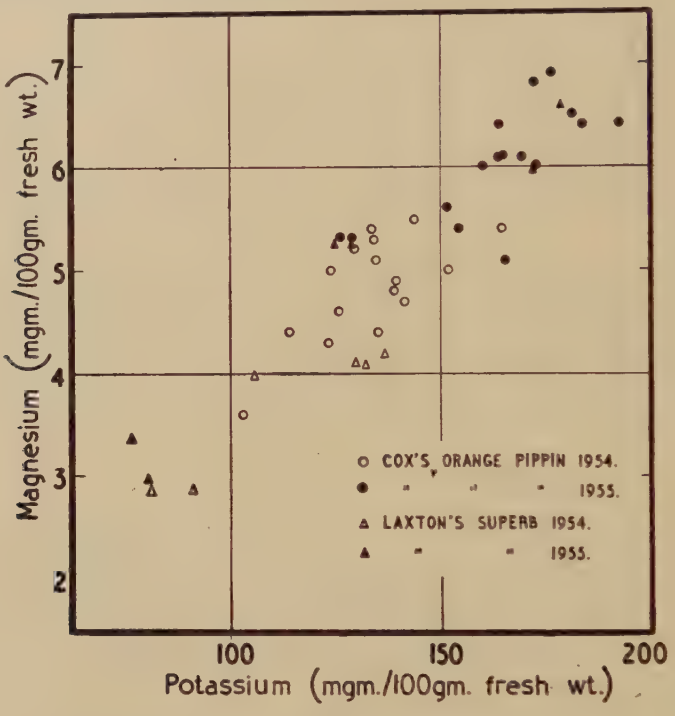

FIG. 3.

Relationship between magnesium and potassium in the fruit.

Apart from its importance as a constituent of chlorophyll, little is known about the rôle of magnesium in the plant. The results under discussion suggest that ionic magnesium may be involved in the buffer system and may be attracted to regions of high acidity. Whether the magnesium moves under the direct influence of potassium, or whether magnesium is built up indirectly because of the acidity (itself dependent on potassium), is a matter for speculation. A knowledge of the changes in composition of the fruit during development, and of the changes in surrounding tissues, might throw light on this.

SUMMARY.

1. From figures previously given for the composition of Cox's Orange Pippin apples from a manurial trial it is concluded that, at the time of picking, pH varies only slightly and that increasing potassium concentration is closely associated with increasing titratable acidity.

2. Similar trends were shown by Laxton's Superb apples from a cover crop trial.

3. These results give experimental support to the view that the relationship of potassium to malic acid in the apple is that of a simple buffer system.

4. There was a parallel trend between the potassium and magnesium concentrations in the samples, and it is suggested that this may in part explain the fact that magnesium deficiency symptoms are sometimes associated with high potash applications.

ACKNOWLEDGMENTS.

This work was carried out as part of the programme of the Food Investigation Organization of the Department of Scientific and Industrial Research ; it is also part of a programme of joint work with the East Malling Research Station. It was assisted in the early stages by an Agricultural Research Council grant. Potassium and magnesium estimations were made by Mr. M. A. Perring.

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(*Received* 23/4/57.)

AN AUTOMATIC DEVICE FOR THE CONTROL OF DAY LENGTH

By R. H. M. LANGER and R. J. CANAWAY
The Grassland Research Institute, Hurley, Berkshire

In studies of photoperiodism it is often difficult to ensure that, over a period of several weeks, plants are exposed alternately to light and darkness at regular intervals. Unless experiments are conducted entirely under artificial light in environmental control rooms or cabinets, the plants have either to be moved into dark rooms or covered by a light-proof structure. Either operation has to be performed without fail at definite times of day, a stringent requirement which may on occasion discourage experimenters from exploring the fullest range of treatments.

Several automatic devices for the control of day length have been described in the literature (Kramer, 1947 ; Greulach *et al.*, 1956 ; Heath and Smith, 1957). In these installations a light-proof box is raised or lowered above the experimental plants. When the plants are uncovered, the box hangs suspended from the roof of the greenhouse and will thus cast some shade, even if the effect is minimized by positioning the box well above or to the north of the treated plants. As an alternative to this arrangement, we have designed a device in which a black curtain is automatically drawn up from below the level at which the plants are growing.

The device (Figs. 1 and 2) is fitted on an ordinary greenhouse trolley (2 ft. 6 in. $\times$ 4 ft. 3 in.) made of angle iron or Dexion-type material, which is continued above into a framework about 2 ft. 6 in. high. The top of the framework is faced all the way round by a double strip of sheet iron approximately 4 in. wide ; this forms a light-proof trap into which the top edge of the curtain fits when it is fully drawn up. The curtain itself is made of black material (Bolton twill) and is suspended from a tubular steel frame which surrounds the trolley.

A superstructure mounted above the framework contains a reversible motor and a steel shaft assembly which act as the raising and lowering mechanism. The shaft assembly consists of two steel shafts (E) mounted at either end of the superstructure so that approximately 4 in. of their length project outwards. The shafts rotate in bearings (C) and are connected by Dunlop flexible couplings (D) and short lengths of steel tubing (F) to the final shaft of a geared, reversible motor which is mounted centrally between and in line with the shafts.

The curtain frame is suspended by two cords from the ends of the steel shafts (G) on either side of the superstructure. When the motor rotates, the cords are wound around the shaft and the curtain is raised. In a similar way a spring-loaded roller blind is drawn across the top of the trolley by means of two cords attached to the shafts between the bearings.

The sequence of operations, from the time that the curtain is up, is as follows. When the time switch (B) reaches the " on " position, the circuit to the relay is closed and the motor is caused to rotate the shaft assembly. As a result the roller blind is released and wound back through the action of its spring. The curtain

around the trolley is lowered and when it reaches a point below the level of the plants, a cord attached to it operates a limit switch which stops the motor. At the end of the light period the relay is released by the time switch and changes over. The roller blind is drawn across and the curtain rises until its frame presses against a rod attached to the limit switch. This completes the operation and the trolley is now completely darkened.

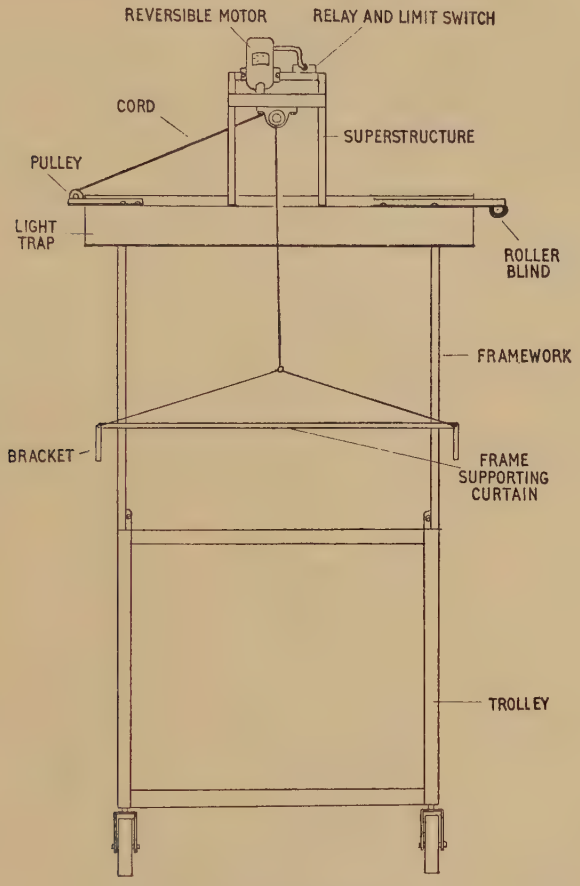

Fig. 1.
Front elevation of apparatus.

Inside the trolley two 4 ft. 40-watt fluorescent tubes and their ballast lamps are mounted. The lighting circuit is controlled by a separate time switch (A), so that the light period may either be composed of full daylight throughout or, preferably in all comparative photoperiodic studies, of a standard period of natural daylight supplemented at either end by artificial light of any desired duration.

The apparatus is kept permanently in a greenhouse. As the light period is usually given during the day, there are only minor differences in temperature between

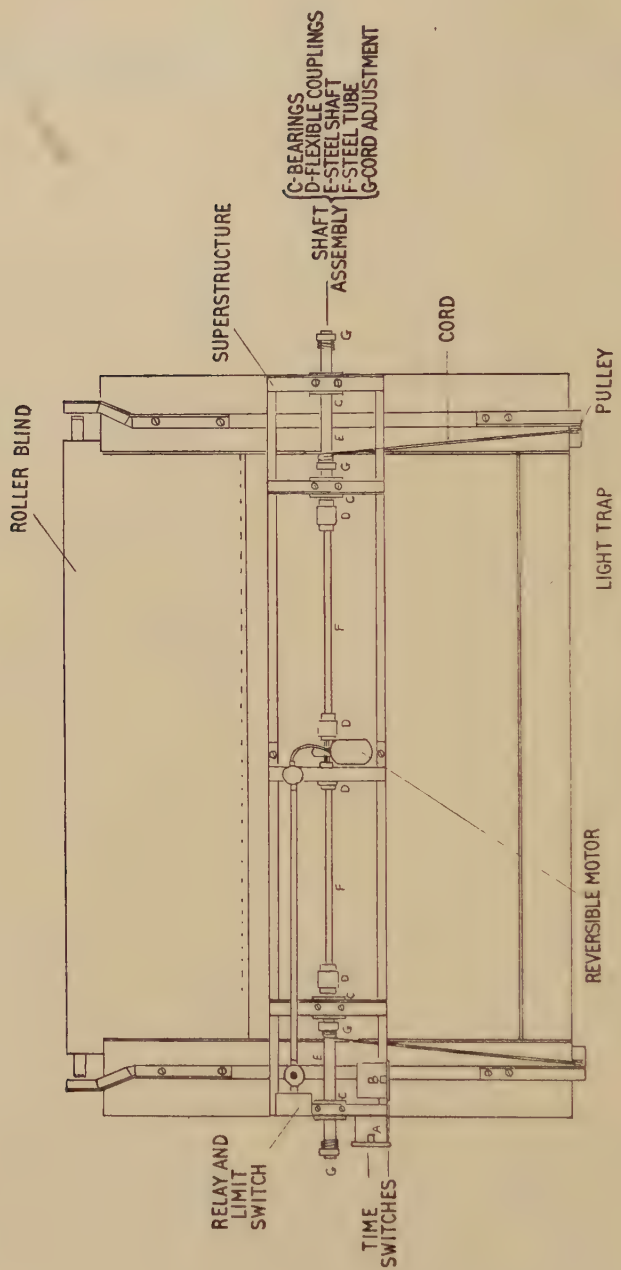

FIG. 2.
Plan of apparatus.

the greenhouse and underneath the dark curtains. The fabric is not rubberized so that air circulation is not seriously impeded. This may have the disadvantage that traces of light might reach the plants, but a light meter sensitive to 0·1 ft.c. has failed to register any light transmission. However, for plants which react to very low light intensities some improvement might be necessary, even at the expense of reducing the circulation of air, although a fan mounted below the plants would help to offset this disadvantage.

SUMMARY.

An automatic device for the control of day length, mounted on a greenhouse trolley with a frame of angle iron above, is described. By means of a reversible motor, geared to a time switch, a black curtain is raised or lowered while a spring-loaded roller blind moves across the top. Supplementary lighting is controlled by a separate time switch.

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(*Received* 31/5/57.)

BOOK REVIEWS

BRITISH TREES. A GUIDE FOR EVERYMAN. By MILES HADFIELD. (London : J. M. Dent & Sons Ltd. 1957. Pp. 448, illus. Price 30s.)

In the delightfully disarming preface the author explains how he " learned something of the private languages that these admirable persons (botanists and foresters) employ to keep their knowledge from the vulgar " and how the fruits of his labours were made available to everyman. In spite of a widespread interest in most aspects of the countryside and the garden, the level of ignorance concerning our trees is astoundingly high, possibly because of the " great gulf fixed " between the one or two pocket books of necessarily limited scope and the large standard works that appear formidable to a potential dendrophile.

Here, however, is a book to bridge the gulf, conveniently sized, reasonably priced, eminently readable and above all profusely illustrated by the author's own pen drawings, in which the natural vigour and grace of the subjects are entirely unspoiled, although accurate attention is given to detail ; the inclusion of typical seedlings is an asset. Such illustrations with their clear annotation obviate the necessity for lengthy morphological descriptions. The subject matter, grouped according to natural families, covers most of the species and varieties of trees, native and introduced, that everyman is likely to meet in forests, woodlands, parks and gardens. In the *Salicaceae*, the willows are given rather a small representation compared with the poplars, but admittedly their bewildering variety calls for a monograph. The account of each tree species includes brief but adequate remarks on its morphology, and information on its biology, geographical distribution, propagation and economic importance, often with the addition of very interesting historical and etymological details. Fruit trees are of necessity treated somewhat more generally but a very judicious selection of material is presented on this vast subject. If everyman will take the trouble to read the author's introduction his enjoyment of the book will be enhanced. He will be grateful too for the appended botanical glossary and entertained as well as instructed by the annotated translations of Latin specific names. The author acknowledges his indebtedness to many authorities included in his useful bibliography, but one feels strongly that his own patient study of, and intimate acquaintance with, the living trees themselves have been the major factors in producing this excellent book.

K.H.C.

HERBACEOUS GARDEN FLORA. By F. K. MAKINS. (London : J. M. Dent & Sons Ltd. 1957. Pp. 356, illus. Price 35s.)

Gardeners with botanical leanings must often have suffered frustration in hunting for means of identifying or attempting to classify some of their less common herbaceous plants. While the wild flora of Britain has inspired a lengthy list of books for the layman, its garden flora can boast scarcely any, apart from the costly standard works in several volumes ; so this posthumous publication from an author

who had already produced *The identification of trees and shrubs* (1948) will indeed be welcomed by those with some knowledge of floral morphology, or with a will to learn enough of it to use the family and generic keys which are an important feature of the book. The comprehensive glossary which precedes these makes them far less formidable than they at first appear.

The bulk of the book consists of very clear line drawings of flowers and inflorescences of 991 different species, grouped according to natural families. In many cases there are inset enlargements of structural details. These are largely self-explanatory, but in some instances a brief annotation would have helped the untrained in deciding precisely which organs have been selected and in what position they are shown. Then follow 2–3-line descriptions of the plants, in the same sequence as the illustrations, marking in most cases the accented syllable in each Latin name. In those unmarked the accent is presumed to be obvious, but this is rather a rash presumption in some cases. The four half-tone plates of gardens successfully tip the balance of the book away from possible austerity, but the six half-plate photographs of individual species need cross references from illustration to description and *vice versa*. How one wishes all the photographs were in true-to-life colour, and what pleasure the delicate-fingered could get by using living specimens as a guide and water-colour tinting the drawings a few at a time! The list of 55 reference books unfortunately does not give publication details, but very usefully mentions the types of illustrations included.

K.H.C.

HOP GROWING AND DRYING. Ministry of Agriculture Bulletin No. 164. (London: H.M. Stationery Office. 1957. Pp. 62, illus. Price 5s.)

Over thirty years have elapsed since the publication of the last Ministry of Agriculture bulletin on hop growing. In this time the basic arts and skills associated with this highly specialized craft have changed but little. The period has been notable however for many advances in the knowledge of the cultural requirements of the crop, in methods of drying and in the control of insect pests and diseases. Many new varieties have been produced and one new and devastating disease, Verticillium Wilt, has arisen and necessitated a re-appraisal of the use of new varieties and methods of propagation.

During this time, the work of Dr. A. H. Burgess of Wye College has been pre-eminent in the realm of hop culture and it is particularly appropriate that he should have written the section of the present bulletin that deals with this. Dr. H. H. Glasscock and Mr. B. D. Moreton, who contribute the sections on diseases and pests respectively, are officers of the National Agricultural Advisory Service with wide experience of these aspects of hop growing.

The botany of the plant is described, followed by an account of varieties, propagation, choice of site and the establishment of a hop garden. Much of the information given will not be new to the experienced hop grower although of considerable value to the student. The subsequent chapters on nutrition, picking and drying contain recommendations based on research at Wye College and hop growers will find them a useful summary of the latest information. Little is said about machine picking, a subject that is engaging the attention of more and more growers, but references are given to recent publications on this subject. There is also a bibliography of the recent research on hop culture.

The next section of the bulletin contains descriptions of all the important diseases of the hop. It is perhaps most indicative of the changes in this field since the last bulletin was published that the now widespread Downy Mildew disease had then been newly reported. The control measure now recommended for the disease, in addition to the removal of infected " spikes ", etc., is the use of bordeaux mixture, a preparation which, although very effective, has tended to be less widely used of late, owing to the development of " single-mix " copper compounds. Brief reference is made to these but no details are given of the rates and times of application.

Of the other diseases, Verticillium Wilt and the virus disease Nettlehead cause the greatest losses and unfortunately no really effective control is yet possible for either, although they can be checked somewhat by the prompt removal of infected plants. Reference is made to the use of wilt-tolerant varieties in affected gardens but no such variety has yet proved entirely acceptable for brewing.

There is no bibliography relating to the disease section and since the information given is necessarily condensed some reference to the available literature might have been of assistance to growers.

It is perhaps in the section dealing with hop pests that the greatest advances in control measures are obvious. In the past few years the methods of eliminating hop damson aphid and red spider have been completely revolutionized by the advent of systemic insecticides. The use of DDT and BHC also renders the control of other hop pests more effective than hitherto. The latest treatments are very fully described in the bulletin.

The publication fills a long-felt want for a comprehensive reference work for hop growers and, though the information is often condensed, it will be of considerable value both to them and to the prospective hop grower or advisory officer.

W.G.K.

TOMATOES. Ministry of Agriculture Bulletin No. 77. 4th Edition. (London : H.M. Stationery Office. 1957. Pp. 72, illus. Price 12s. 6d.)

The fourth edition of this Bulletin has been revised, most sections being rearranged and expanded in the light of post-war developments, such as the use of first cross hybrids and the economic and cultural considerations in favour of the east-west orientation of propagation houses ; some additional information, especially on the collection of seed and artificial illumination, increases its scope. It is unfortunate, however, that there are still some noteworthy omissions. Recent work on the influence of temperature on the initiation and number of flowers in the first three trusses is not mentioned ; i.e. with a high mean day and night temperature more leaves are formed before the first flower truss, whereas low day and night temperatures favour formation of the maximum number of flowers. Again, there is no guidance concerning soil warming prior to planting, usually achieved by heating the glasshouses for from one to three weeks, though soil heating by electricity is quicker, cheaper and more efficient.

Nevertheless, like other of the Ministry's Bulletins, at its price this one is invaluable for commercial growers and should be studied by all those engaged in the culture of the foremost glasshouse crop.

M.M.M.

THE COX'S ORANGE PIPPIN. By D. Macer Wright. (London: Faber & Faber Ltd. 1957. Pp. 119, illus. Price 15s.)

Although there are many varieties of apples which require individual cultural treatment for the best results, Cox's Orange Pippin is probably the most important in this respect, even if it is regarded, perhaps with some justification, as being—for want of a better term—temperamental. In this book Mr. Wright sets out to describe in detail the methods he recommends to obtain the best results.

Chapters I and II deal with soils and the management thereof. Emphasis is laid on the need for adequate drainage. Suggestions are made for dealing with existing soils, with due regard to building up soil fertility for the production of healthy well-grown trees. The need for humus is stressed and various recommendations are made for supplying this. Mulching, cover cropping and grassing down are discussed in some detail. "The ultimate aim", says Mr. Wright. "in the first phase of soil management in a Cox orchard is the establishment of a good sward. Cox trees growing in well-tended grass will, on the whole, produce the best crops. The fruit will be finely coloured, of the right texture, flavour will reach the highest standard, and the keeping qualities of the fruit will be much improved." Few will contradict this statement.

A short chapter on fertilizers and their uses is followed by one on mineral deficiencies and excesses, and Mr. Wright has presumably drawn on his own experiences as well as on the findings of the research stations.

In considering a site for a Cox orchard, the requirements of the amateur and the commercial grower are compared.

In Chapter VI the correct procedures for planting and staking are clearly demonstrated by line drawings.

Two chapters deal with the chief insect pests and diseases, and with methods of combating them. There are also some interesting remarks on insect friends, in which the use of DDT after the green cluster stage is strongly deprecated.

Rootstocks and planting distances combine to make one chapter. The forms of tree and the appropriate rootstocks are discussed, the difficulties associated with M.IX being rightly set forth and emphasized. Until some of the newer rootstocks come into more common use, only M.IX, M.VII and M.II are advocated.

In Chapters X and XI, pruning in principle and in practice are described in detail and illustrated. Careful reading of all that is here explained should give the inexperienced reader an insight into what is usually regarded as a mysterious and sometimes even a controversial subject.

In another chapter on picking and storing, although the use of slatted fruit trays sometimes is suggested, the author emphasizes the necessity for the right atmospheric conditions.

There are useful short chapters on pollination and on methods of dealing with the neglected tree.

Mr. Wright is most fortunate in being able to include the very interesting article, by Mr. Simmonds of the Royal Horticultural Society, on the origin of this apple; this even includes some details about Mr. Cox's family history.

Some up-to-date recommendations about spraying, neatly compiled for easy reference, are given together with notes on bud and blossom stages for pest control measures.

The index might well be less sparse. Some growers will think it a pity that the coloured plate, forming the book cover, of a young well-fruited bush shows it to be in proximity to what appears to be a heavily timbered wood!

This book, with only one or two printers' errors, makes good reading and, although Mr. Wright mentions that it is intended for the amateur, I think commercial growers will read what he has to say with interest even if they do not always agree with his recommendations.

H.H.C.

PLANT PROPAGATION. By JOHN P. MAHLSTEDE and ERNEST S. HABER. (New York: John Wiley & Sons, Inc.; London: Chapman & Hall, Ltd. 1957. Pp. 413, illus. Price 60s.)

The authors of this book state that their primary purpose in writing it is to acquaint the student of plant propagation with the application of the scientific facts and principles that are involved in the increase of plant numbers. They have succeeded in their objective. The book is divided into five parts. Part One, which deals with basic concepts and principles, includes a chapter on the botanical and horticultural classification of plants. This is followed by a brief but adequate description of vascular plants and of plant growth and development. Part Two is devoted to the sexual propagation of plants, beginning with a very full exposition of the origin and development of a seed and then going on to describe the harvesting and cleaning, under American conditions, of flower and vegetable seeds, and of the seeds of trees and shrubs. Treatments to facilitate germination and the factors influencing propagation by seed receive detailed consideration, and a discussion on the functions and desirable characteristics of the media used for seed germination and the rooting of cuttings is given a chapter to itself.

Part Three describes vegetative propagation. Details are given of ways of increasing stocks of bulbs and related plant structures; of methods employed in layering (including air layering) and of striking root, stem, leaf and leaf-bud cuttings; and of the highly successful method of intermittent mist propagation now practised with the help of that ingenious device the electronic leaf. A succinct review of the uses of growth-controlling substances in plant propagation is followed by a long chapter on grafting and budding.

Nicolieren and Garner budding techniques designed to overcome incompatibility between quince and certain pear varieties are described, as are some other types of budding not generally employed in this country. More space might have been devoted to the top-working and frameworking of fruit trees. The oblique cleft, crown, and inverted L grafts are not mentioned. In a chapter on rootstocks, observations are included on the performance of Malling rootstocks in America, and reference is made to the most useful of the Malling-Merton series. Mound layering (stooling) gets its fair share of space, but nothing is said about the etiolation method of layering.

In Part Four the various propagating structures in use in the U.S.A. are described and several are illustrated, while Part Five is given over to the propagation of specific plants. It is surprising to find on page 382 a paragraph on brick spawn used in mushroom growing, but abandoned in England years ago.

There are sixteen useful tables, plus three that constitute an appendix, and a good index. Most of the selected references given at the end of each chapter are

American, but it is gratifying to find some of the Annual Reports of the East Malling Research Station, and " The Grafter's Handbook " by R. J. Garner, recommended for further reading.

The book provides a tremendous amount of valuable information, most of which can be applied on this side of the Atlantic. It is written in English that is crystal clear and its production leaves nothing to be desired, except that some of the photographs are a little grey and indistinct. Its price, 60s., means very probably that it will not appear on the shelves of many private libraries, but it should certainly be found on those of all teaching institutions concerned with horticulture.

H.F.

CITRUS GROWING IN AUSTRALIA. By F. T. Bowman. (Sydney, London, Melbourne, Wellington: Angus and Robertson. 1957. Pp. 311, illus. Price 63s. (sterling).)

" The editor " of the *Australian Agricultural and Livestock Series*, to which this book belongs, has " laid down as guiding principles that the text should be concise, Australian in treatment and, while incorporating the findings of the latest research, practical in outlook." So writes Dr. Bowman in his preface and then proceeds to do exactly what the editor asks in producing the first general reference book on citrus growing in Australia.

Following a brief history of the industry he devotes three chapters to the complexities of varieties, species and hybrids, to the selection of varieties and rootstocks, and to methods of propagation. Between them these chapters cover such matters as bud sports and nucellar seedlings, virus and other diseases, and the effects of different rootstocks on tree growth and fruit quality. From nursery practices Dr. Bowman passes on to consider climatic, soil and other factors which govern the choice of districts for planting citrus and then to the selection, design and development of a site with emphasis on the layout of drains and irrigation systems. Planting, both in straight rows and on the contour, is described, and a whole chapter is devoted to the development and care of young trees up to bearing age.

The six remaining chapters concern the management of bearing groves. They include recommendations on nutrition, with descriptions of symptoms of mineral deficiency and toxicity, soil management, irrigation, and pest, disease and frost treatments. A chapter on pruning lays particular stress on methods of renovating older trees, and another on cropping discusses flower and fruit development and means of reducing fruit drop. Finally, harvesting and the preparation of fruit for market are dealt with.

For a text book designed for use by students and by growers, large and small, the sequence outlined above is admirable. The story is told with clarity, although with a degree of conciseness amounting almost to terseness in some places. The results of Australian research up to 1955 are incorporated in so far as they have a practical application, but experience obtained in other countries is used only to fill in gaps in knowledge.

The book, which is well printed and illustrated, provides the Australian citrus grower with a standard work which will be of value for many years to come. The grower in other countries, who makes allowance for its regional approach, will also find that it contains much information of interest. The price may seem high, but the diet is concentrated.

G.K.A.

DECIDUOUS ORCHARDS. By W. H. CHANDLER. 3rd Edition. (London : Henry Kimpton. 1957. Pp. 492, illus. Price 56s.)

That this book, first published in 1941, is now in its third edition is sufficient evidence that it has proved a useful text. Its great value lies in the fact that the treatment is based on physiological principles rather than on techniques, and it thus attempts so far as possible to interpret horticultural practice in the light of an understanding of how the plant works.

In the first edition no attempt was made to review the evidence or to cite the source of experimental data. In this new edition the value of the book has been considerably enhanced, especially to the student, by this supplementation of the text. The list of references does not pretend to be exhaustive ; the author has been selective, choosing so far as possible those papers which are likely to be readily available in any good working library. They are confined to publications in English, but nearly as many are cited from British journals as from American.

The general arrangement of the book remains unchanged. Part I is devoted to a discussion of the structure and physiology of the tree and Part II to the environment in which it grows, both climatic and edaphic. Part III deals with the principles of orchard practices, including propagation, planting and pruning systems, while Part IV is devoted to the individual fruits, starting with the pome and stone fruits and going on to mulberries, figs, some sub-tropical fruits and the edible nuts, and concluding with a chapter on the tung-oil tree.

Its only American competitor in readability and value as a book for understanding the problems of deciduous fruit growing is Gourley and Howlett's book, now becoming somewhat out of date. It is a book which may safely be recommended to the student and which should be read by every progressive fruit grower.

R.H.S.

NOTICE TO CONTRIBUTORS

1. All **manuscripts** should be in double-spaced typewriting, with a good margin, and should be addressed to the Editor, East Malling Research Station, near Maidstone, Kent, England. Papers must be written concisely. Historical reviews should be as short as possible and only such references to literature as bear directly on the subject should be included. Tables and illustrations, if any, must be only such as are absolutely essential for clear presentation.

2. Authors of papers containing extensive **numerical observations** should consult the recommendations of the British Association Committee on Biological Measurements, 1927, obtainable from Burlington House, London, W.1, price 6d. Arrangements have been made whereby original data too extensive for complete publication may be deposited at the British Museum (Natural History), London, S.W.7, or with the Royal Society of Edinburgh, 22 George Street, and thus be available for consultation by other workers. Full bibliographical reference to the publication in which the results are summarized must be supplied with the data.

3. Each paper must conclude with a concise and critically correct **summary** of its actual content. It should contain any new or verified constants as well as any other critical data of permanent value but not tables or graphs. Any organism mentioned should be given its scientific name.

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PRINTED BY HEADLEY BROTHERS LTD 109 KINGSWAY LONDON WC2 AND ASHFORD KENT